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Civil Defense Shelters
A State-of-the-Art Assessment—1986

C. V. Chester
G. P. Zimmerman

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The literature on the design, construction, testing, and cost of blast and fallout shelters was reviewed and a bibliography of over 1000 documents was assembled. It was found that nuclear weapon effects and shelter design are well understood. The principal technical barrier to construction of permanent shelters is cost. Single-purpose blast shelters cost in the high hundreds to low thousands of dollars per space, depending on size, hardness, location, and whether the shelter is part of new construction or retrofit. The risk area

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population requiring blast protection is approximately 160 million.

The very low cost (and less effective) options open to the U.S. Government, with its present civil defense budget, remain: (1) maintain the inventory on fallout shelter and identify space with some blast protection potential; (2) plan for "crisis upgrading" to improve existing space in a crisis, and (3) plan for construction of expedient shelter in a crisis. Fallout shelter might be mandated in appropriate new construction outside risk areas at little cost to the government.

Options in the mid-range of expense, a few tens to a few hundreds of dollars per space include: (1) requiring modified limestone mining practices, where appropriate, to generate useable shelter space near cities; (2) encouraging the construction of earth-sheltered housing and other buildings, and (3) requiring and/or subsidizing the construction of dual-use basement shelter in new construction. A program based on these options would require an annual budget approximating 1 per cent of the yearly defense budget for the next 20 years. Keywords:

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CIVIL DEFENSE SHELTERS

A STATE-OF-THE-ART ASSESSMENT -- 1986

C. V. Chester
G. P. Zimmerman

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CONTENTS

CONTENTS
(Continued)

CONTENTS
(Continued)

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EXECUTIVE SUMMARY

This report is a comprehensive review of what is known about shelters from the available literature in the United States. An attempt has been made to concentrate on the information which should be known by a U.S. planner. Shelter against a number of natural and technological hazards is considered, but the most important threat, and the one about which the most information exists, is shelter against nuclear weapons effects.

The most important fact to recognize is that there is a very well developed technology for the protection of civilians against the effects of nuclear weapons. It is potentially very effective and has been extensively tested against real nuclear weapons in the 1950s and, subsequently, blast tested with large high-explosive charges and shock simulation techniques. Design techniques are covered in a variety of manuals, and all such techniques will produce shelters that will be very highly effective. In the past, the reliability of design was often attained at the cost of great conservatism and excessive expense. The present state of the art in structural design of blast shelters is comprehensively described in the 1985 update of the American Society of Civil Engineers' Manual No. 42, Design of Structures to Resist Nuclear Weapon Effects.

The threat to the American public from nuclear weapons is now believed to be of such magnitude that a full shelter program would have to include 160 million blast-shelter spaces and approximately 80 million fallout-shelter spaces. Blast protection is believed to be required in the areas surrounding military targets and urban-industrial areas. Fallout protection is believed to be required over the entire country.

Existing structures, particularly large masonry or concrete buildings, can provide significant, though varying, amounts of fallout protection. An effort by the U.S. Government to identify such structures in the 1960s and 1970s, has identified an inventory of 245 million spaces which can provide protection factors of 40 or more against fallout radiation. Unfortunately, most of these spaces are in what are presently believed to be risk areas, and many of them are in the upper stories of multistory buildings, which are vulnerable to blast effects. The basements of concrete buildings provide some protection against blast effects but only at low overpressures. There is not nearly enough of this "best available" space to protect more than a very small fraction of the risk area population. With today's resources, the only hope of survival of the risk area population in an all-out attack would be a large-scale evacuation of the target areas during the days preceding the attack.

If several hours' or days' warning of an attack are available, highly effective fallout shelter can be improvised. This protection can include improvisation of shelter in a basement by stacking books, furniture, bags and boxes of earth, and other mass on and around a table in a protected corner.

In the 1970s, a technology for producing effective shelter from tools, materials, and labor at hand was developed. This technique called "expedient shelter" involved the construction of covered foxholes or covered trenches. All these shelters provide fallout protection factors in excess of 100. In the Defense Nuclear Agency's 600-ton, high-explosive field tests, the designs using unshored trenches survived blast overpressures in the region of 5 to 7 psi. Lightly-shored versions survived 15 or more psi and one design has repeatedly survived overpressures in excess of 50 psi. If the information on construction of these shelters can be disseminated to the public, and 24 to 48 hours are available for construction, very good protection can be developed for very large numbers of people. For the foreseeable future, this expedient, self-help alternative is all they are likely to have.

Far more people would survive a rapidly-developing nuclear war if shelter were already in place before the onset of a nuclear crisis. One of the major deterrents to a program that would provide shelter for all Americans is its cost which will be the product of the cost per space times the number of spaces needed. In the case of blast shelters, the number of spaces needed is approximately 160 million. Fallout shelter spaces needed are approximately 80 million. Single-purpose, small blast shelters can cost from $500 to $2500 or more per space, with $1000 being representative. Blast shelters built into the basements of new construction can be constructed for $250 to $500 per space, with $300 being a good representative figure. Fallout shelter built into new masonry construction may cost only about $50 per space. Slightly altering new construction to make maximum use of features which would have been constructed in any case, such as basements, is called "slanting." This technique is by far the most cost-effective approach to developing shelter.

Construction with the potential for blast slanting includes basements of masonry buildings with concrete first floors, schools and residences designed partially or wholly underground for energy conservation, aesthetics, or tornado protection, and underground mining operations for the production of concrete aggregate or agricultural limestone.

A shelter program based on blast and fallout slanting in new construction would entail an annual expenditure of approximately

1% (continued over ten or more years) of the annual Department of Defense budget. Funding at this level might be considered if this country were to adopt a defensive strategic posture. However, for the present, while we know how to build shelters, we have not solved the political problem of allocating the resources to get them built.

CONVERSION FACTORS FOR SI UNITS

English units have been retained in the body of this report. The report refers to commercially available materials and sizes commonly expressed in English units. The report reviews earlier work expressed entirely in English units. Conversion factors for SI units are given below:

To convert from:	To:	Multiply By:
atmosphere (14.7 psi)	kilopascal (kPa)	101.325
cubic feet (ft^3 or cu ft)	cubic meter (m^3)	0.0283
foot (ft)	meter (m)	0.3048
footcandle	lumen/meter^2(lm/m^2)	10.764
gallon (gal)	cubic meter (m^3)	0.003785
gravity (32.174 ft/sec^2)	meter/sec^2(m/s^2)	9.80665
inch (in.)	meter (m)	0.0254
mile (mi)	meter (m)	1609.3
pound-force/in^2 (psi)	kilopascal (kPa)	6.8948
quart (qt.)	cubic meter (m^3)	$9.464X10^{-4}$
square foot (ft^2, sq ft)	square meter (m^2)	0.0929
square mile (mi^2)	square meter (m^2)	$2.59X10^6$
ton (nuclear equivalent of TNT)	joule (J)	$4.20X10^9$
ton (2000 pounds)	kilograms (Kg)	907.185

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LIST OF FIGURES

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(Continued)

LIST OF FIGURES
(Continued)

LIST OF TABLES

ABSTRACT

The literature on the design, construction, testing, and cost of blast and fallout shelters was reviewed, and a bibliography of over 1000 documents was assembled. It was found that nuclear weapon effects and shelter design are well understood. The definitive state of the art in structural design of blast shelters is comprehensively described in the 1985 update of the American Society of Civil Engineers Manual No. 42, Design of Structures to Resist Nuclear Weapons Effects.

An important barrier to construction of permanent shelters is cost. Single-purpose shelters cost in the high hundreds to low thousands of dollars per occupant (or per space), depending on size, hardness, location, and whether the shelter is part of new construction or retrofit. Multiplied by a risk area population of approximately 160 million, the cost of a blast shelter construction program would rival that of a major strategic weapon system.

Options in the mid-range of expense, a few tens to a few hundreds of dollars per space include (1) requiring modified limestone mining practices, where appropriate, to generate usable shelter space near cities; (2) encouraging the construction of earth-sheltered housing and other buildings; and (3) requiring and/or subsidizing the construction of dual-use basement shelter in new construction. A program using this approach would require an annual expenditure of approximately 1% of the annual defense budget for 10 or more years.

The very low-cost (and less effective) options open to the U.S. government, with its present civil defense budget, remain as follows: (1) maintain the inventory of fallout shelters and identify space with some blast protection potential, (2) plan for "crisis upgrading" to improve existing space in a crisis, and (3) plan for construction of expedient shelters in a crisis. The crisis-implemented options require several days' warning in order to be effective.

While much of the technology for protecting people against nuclear weapons effects originated in this country, we have not solved the political problem of allocating the resources to protect our own population.

CIVIL DEFENSE SHELTERS - 1986
STATE-OF-THE-ART ASSESSMENT

C. V. Chester
G. P. Zimmerman

1. INTRODUCTION

1.1 WHAT ARE WE TRYING TO DO?

This literature review is one of several being sponsored by the Federal Emergency Management Agency (FEMA). The purpose of these reviews is several fold:

1. To summarize in a useful form the most important results of research sponsored by FEMA and its predecessor agencies over the past four decades. In particular, it would provide understanding of the most important results for recently appointed civil defense decision makers.

2. Where appropriate, to identify and highlight results which could be, but are not being, utilized in the present FEMA programs and policies. Results which support (or oppose) the credibility of FEMA programs are examples.

3. To identify important questions which are not addressed by the present body of research and for which answers are needed.

1.2 WHY BOTHER?

In the present (mid-1980s) political and economic climate, investment in a major shelter building program is very unlikely. With the U.S. Congress and the Administration struggling with deficits of $200 billion and attempts to sustain or increase the defense budget, undertaking a program which could lead to expenses in excess of $100 billion to deal with an event considered to be of very low probability is unlikely, so why bother with this study?

- Nuclear weapons are not likely to go away.

- A great deal of money was invested by the Federal government in developing the technology for protecting people against weapons effects. We should try to preserve that technology.

- We (FEMA and ORNL) receive a continuing stream of requests by citizens for information on shelter.

- The political climate may change. Interest in protection of our civilian population against nuclear weapons effects may be sharply increased by any one of a possible number of events.

- Nuclear weapons may be used in countries other than the United States and the Soviet Union. Efforts to acquire nuclear weapons on the part of some of the less stable developing nations in places like the Mideast are continuing. Actual use of such weapons by either recognized governments or terrorists could alter American views on the value of having protection against prompt nuclear weapon effects for our citizens.

- The United States could suffer a massive diplomatic defeat at the hands of the Soviet Union due to the lack of protection the American civilian population has, compared to that of the Soviet Union. An example might be a confrontation in the Persian Gulf or Western Europe resolved in favor of the Soviet Union because of its perceived capability to put its citizens in a more protected posture than is feasible in the United States.

- The President's effort to find a technological fix to the arms race through the Strategic Defense Initiative may be successful. Shelter deployment in conjunction with an active defense which is over 90% effective can itself be more cost-effective at the margin than the active defense in increasing the number of survivors of a large attack.

1.3 WORK STATEMENT

The work statement for this program is:

> "Topics for which state-of-the-art assessments of available research will be conducted include . . . <u>shelter</u>, to include requirements for all hazards that may require sheltering for elements of the civil population for rotection from blast, fallout, nuclear accidents, hazardous materials, or weather hazards, and further including dedicated, multiple-use and special purpose shelters.

> The assessment shall cover permanent, expedient construction, upgrading and modification of existing structures, potential use of natural shelter such as caves and mines, and information concerning performance of structural components of shelters. Aspects of the shelter problem covered shall include as available in the research literature, requirements, current inventories, options for increasing available shelter capacity, and cost estimates associated with different shelter options."

1.4 APPROACH

The literature on shelter is large and diffuse. It consists principally of government reports sponsored by FEMA and its predecessors, the Atomic Energy Commission, and the Defense Nuclear Agency and its predecessors. There is no comprehensive bibliography of reports on shelter. A search of the Defense Technical Information Center under the title of "Shelter" produces a listing of approximately 3,000 entries, most of which are tangential to our concern--shelters for civilians against nuclear attack.

FEMA has a computerized list of their research reports extending back to 1972. Unfortunately, much of the work on weapons testing of personnel shelters was done late in the 1950s and early 1960s prior to the Test Ban Treaty in 1963, and most of the work on shelter development and shelter system analysis was done from 1963 to 1972 with the relatively large civil defense budgets at that time.

A very useful source of documents is the recently computerized card catalog of the Emergency Technology Library at the Oak Ridge National Laboratory. This library contains all of the holdings accumulated by the Oak Ridge Civil Defense Research Project from 1964 to 1972 and its organizational successors extending to the present time. This collection, while not complete, contains many documents which are available in very few other places. It inherited the documents collected by the library of Project Harbor in 1963 which includes a set of the United States Strategic Bombing Survey documents and the Atomic Energy Weapons Test Report Series.

Documents selected from the various bibliographical sources were physically obtained and reviewed for pertinence. Cards were made out on them and they were assigned to one or more sections of the outline of the final report.

No attempt has been made in this report to describe each of the more than 1000 documents in the bibliography. Instead an effort has been made to describe only the most important documents on the most important topics in shelter. Other documents bearing on the subject are listed at the end of each section. We have attempted to provide a key to most of the U.S. shelter literature.

We have attempted to produce a brief document which can be read by a decision maker in a reasonable amount of time to introduce him (or her) to the most important aspects of the subject of shelter for civilians against hazards, especially nuclear weapons effects. Where possible, we have tried to reference summaries and surveys rather than all of the original sources. If the reader wants more detail he can refer to the documents listed in the bibliography.

The logic of the report is to describe the state of knowledge about the threat (Chapters 2 and 3), the technology to deal with it (Chapters 4 and 5), the requirements for shelters (Chapter 6), and the choices the decision-maker (or individual) has to satisfy the shelter requirements and what the trade-offs are (Chapter 7 and 8).

1.5 STATE OF KNOWLEDGE

Seeking or constructing shelter against a lethal environment is an activity of man that is older than recorded history. Seeking shelter in caves from human and animal predators or weather predates stone-age technology. The construction of castles, field fortifications, and earth works against projectiles (arrows and stones) existed before the age of gunpowder.

The concept of engineered structures to protect against artillery can be said to have begun in the late 17th century by the Marquis de Vaubain. Field fortifications using overhead protection against high-trajectory artillery fire were used to some extent in the American Civil War. In World War I the intense use of artillery and the beginning of aerial bombardment led to the extensive use of field fortifications with massive overhead protection. Development between the wars led to the refinement of modern protective construction against modern conventional weapons. This technology made extensive use of armor plate and reinforced concrete which was developed late in the 19th century. The design procedures for reinforced concrete also underwent a great deal of development between the world wars.

Well-known examples of this technology were the Maginot Line between France and Germany and the Fort of Eban Emael on the Belgian frontier. Although these fortifications were outflanked and neutralized by brilliant unconventional tactics and audacity in the German Blitzkrieg in 1940, their ability to protect their inhabitants against bombardment was never challenged. Indeed the manifest strength of the fortifications effectively deterred frontal assault.

Shelters to protect civilians against blast and fragments became highly developed in World War II. Generally known as "bomb shelters" the structures included blast doors, protection against chemical agents, and the use of subsurface construction. Germany in particular developed some very effective technology against aerial weapons since it was subjected to very heavy bombing (U.S. Strategic Bombing Survey, October 1945, January 1947). Notably effective were their designs for civilian shelters called "bunkers" and their construction of massive concrete protective structures for their submarine pens.

The German "Sonnenbunkers" were aboveground reinforced concrete buildings designed to resist direct hits from aerial bombs; originally 500-lb. and eventually 2000-lb. and up. These shelters were expensive, requiring up to 3 m^3 of concrete per occupant in the smallest size (500-man) and 1.8 m^3 of concrete in the larger size (40 to 4800-man) even crowded to 5 people per square meter.

It was decided early on that bunkers could not be afforded for the entire population but would be restricted to 5% of the population of some 70 cities designated as strategic targets. However, by 1944 bunker space existed for about 15% of the population of those cities. Crowding factors of 4 or 5 are reported (which doesn't seem possible if the design capacity were 5 people per square meter). The rest of the population had reinforced basements or belowground tunnel shelters.

Few improvements had to be added to the World War II bomb shelters to make them effective against nuclear weapons. The massive concrete and underground construction provided inherent protection against nuclear radiation. High performance shelters against nuclear weapons effects required the addition of radiation protection of the entrances either through more massive doors or entryways with one or more turns in them. The long duration of the blast pressure from large nuclear weapons required the addition of shock isolation inside the shelters to protect against ground motion and the insertion of blast valves in the ventilation air intakes to prevent the shelters from being filled with high pressure air. Filters were generally included to keep out radioactive dust and fallout.

Tests of shelters against low and intermediate range yields (tens to hundreds of kilotons) at more than 1 atmosphere overpressure quickly showed that initial nuclear radiation was an important design parameter requiring several feet of earth cover on the shelter for shielding.

Coincident with the cessation of nuclear testing in the early 1960s, technical developments in shelter for civilians were directed at ways of reducing the costs of shelter rather than improving its protection. It was accepted that it was not cost-effective to seek shelter designs for the civilian population that could survive a very close detonation of nuclear weapons.

With the discovery of fallout from the testing of large-yield weapons, it was recognized that any system of protection would require that the fallout radiation protection be provided to the entire population outside of the target areas.

"Slanting" began to be explored in the 1960s as a means of reducing the cost of shelter for civilians. This technique consists of slightly modifying construction intended primarily for other purposes in such a way that protection against nuclear effects is developed. Basements, subways, and tunnels that are being built for other purposes are candidates for slanting.

Explorations of the potential of "best available" shelter were carried out in the 1960s and 1970s. It was discovered that the basements of buildings, especially those with reinforced concrete first floors, could provide significant protection (12 or more psi) against blast as well as radiation without any modification. People would have to stay out of the entryways where high velocity winds could propel them with lethal velocities against the floor or wall.

This led logically to "upgrading" in which suitably constructed floors were reinforced with movable columns during a crisis. Additional shielding in the form of earth can also be added to the first floor and piled against exposed walls. Given time, the protective capability of a structure not designed as a shelter could be considerably improved.

"Expedient Shelter" became highly developed in the 1970s. This term has been adopted to mean shelter that is constructed during a crisis from materials available with the resources of tools and labor at hand. Most expedient shelter designs are covered trenches with either shored or unshored earth walls. There are aboveground and semiburied versions for regions of high water table. Most are constructed from wood, and all are covered with earth to provide significant radiation protection. The covered trench versions usually provide fallout protection factors above 200. Some versions of expedient shelters have demonstrated survival of blast overpressures in excess of 100 psi.

The ability of buried timber shelters and buried corrugated metal culvert to survive very high overpressures is due to the phenomenon of earth arching. When these types of structures are buried in the right type of soil, the applied blast load is partly carried by the soil. The understanding of this phenomenon was improved in the 1960s and 1970s, and models useful for two-dimensional calculations have been developed. They are not useful for predicting failure pressures except to recognize that these pressures are large.

Shelter against the effects of nuclear weapons can be considered a quite mature technology. Shelters can be designed from a variety of materials at a variety of costs and can be expected to function reliably with high confidence. The central problem of shelter construction programs is that any cost per space must be multiplied by approximately 240 million spaces (160 million with blast protection and 80 million with fallout protection). Even the most clever designs still entail significant cost for permanent blast shelter. We know how to build shelter but we have not solved the political problem of allocating the resources to get it built.

2. NATURAL AND TECHNOLOGICAL THREATS

A discussion of shelter must address the question: "shelter against what?" This study is concerned with shelter from life- or health- threatening conditions in the environment. Although the bulk of the examined literature is concerned with protection against the effects of nuclear weapons, there are a variety of peacetime hazards which can result in large-scale disasters (Federal Emergency Management Agency, 1984). Collins (1972) and Quarantelli (1982) have addressed the problems which accompany sheltering the population after such disasters.

2.1 TORNADOES, HURRICANES, AND HIGH WINDS

Atmospheric, weather-related disturbances produce some of the most spectacular peacetime disasters. They are capable of producing dramatic, local property damage anywhere in the entire United States. An average of 150 fatalities per year are produced by tornadoes which can have winds approaching 300 mph (Abbey, 1976). These short-lived storms are the most violent and destructive of all atmospheric phenomena. Storm cellars and covered dugouts have been traditional fixtures on farms in the U.S. central plains, principally for protection against tornadoes. Fatalities of 150 people per year are trivial compared to the fatalities from automobile accidents; however, the effects of tornadoes are so dramatic that people have made considerable investments in protection against them. Earth-sheltered homes and schools (Defense Civil Preparedness Agency, 1973) in the central region of the United States, from Texas to Minnesota, are quite common. Oklahoma, which is the state that has the highest tornado frequency, is also the state with the largest number of earth-sheltered schools (Oklahoma State Department of Education, 1978).

It is virtually impossible to build a frame residence that will survive a severe tornado. Strong, reinforced concrete buildings provide increased resistance (Defense Civil Preparedness Agency, 1976; Federal Emergency Management Agency, 1980b, 1982). Earth-sheltered housing (see Section 7.5.3), and any other belowgrade structure, is virtually immune to the high winds and the very low internal pressures which are responsible for the destruction of conventional structures. Fallout shelters with 300 lb/ft^2 of concrete or earth covering the roof are likewise unlikely to be damaged by tornadoes.

Hurricane damage is limited to the U.S. coastal regions. Adequate protection from hurricane winds can be provided (Spangler and Jones, 1984), but the possibility of flooding precludes the use of belowground shelters.

2.2 NUCLEAR ACCIDENTS

As events at Chernobyl in April 1986 demonstrated, it is possible for a nuclear reactor to undergo accidents which release large amounts of radioactivity to the environment. While the radioactivity released at Chernobyl was a minute fraction of that expected from a ground-burst megaton weapon, it did result in the evacuation of nearby civilian populations as a precaution. Because of organizational and managerial deficiencies, the surrounding population was not made aware of the seriousness of the accident from some time. Had they been notified, they could have taken shelter in basements, fallout shelter areas, and interior portions of their multifamily dwellings and significantly reduced the gamma radiation dose to which they were exposed. Even the most severe hypothetical reactor accident scenarios postulate environmental contamination which is a very small fraction of that which could be produced by widespread nuclear weapon fallout from a war (Nuclear Regulatory Commission, 1976). Any fallout shelter useful against weapons effects will provide more than adequate protection against external gamma radiation doses from any reactor accident.

2.3 TOXIC AEROSOLS AND VAPOR

Unless equipped with appropriately designed filters, fallout and blast shelters provide very little protection against airborne toxic aerosols and toxic vapors. These toxic materials, whether they are toxic chemical vapors from a Bhopal-like incident, radiological aerosols coming from a damaged nuclear reactor, or chemical or biological weapons disseminated by terrorists, are drawn into the shelter with the ventilation air and breathed by the occupants. Particulate filters are available which will remove any toxic aerosol; charcoal filters are available which will remove moderate amounts of most toxic chemical vapors. The better Swiss shelters are equipped with such filters. Particulate filters are relatively inexpensive and are probably a prudent investment to anyone building a fallout or blast shelter. Charcoal filters are much more expensive and are probably unjustified, unless one is building a shelter downwind of a known chemical hazard.

Protection against toxic aerosols and vapors can be obtained in a well constructed modern house, if it is pressurized by a blower drawing air through a filter effective against the expected toxic agent. The blower capacity must exceed the infiltration rate of the house when the doors and windows are closed. (Some protection against toxic aerosols can be obtained by using a household vacuum cleaner as a blower/filter for this purpose.)

Belowground fallout and blast shelters are more easily protected against toxic aerosols because they generally have much slower (almost zero) infiltration rates with the doors and ventilating openings closed off.

2.4 LARGE FIRES

Fires of external origins such as forest fires or those from aircraft crashes occasionally threaten the general public in residential areas. Human casualties are usually very low but property destruction can be quite extensive. Destruction of residential areas due to wildfires is almost an annual occurrence in the western part of the United States. Earth-sheltered houses, and virtually any underground shelter, provide almost complete protection against this hazard, provided that the air supply to the shelter area is not contaminated by smoke or toxic fumes (Broido and McMasters, 1960; Earp, 1953; Irving, 1964; Miller and Kerr, 1965; and Murakoa, 1961).

Well-designed nuclear shelters provide fire protection at a level which exceeds fire codes. This is because fire codes assume the continuing availability of professional fire fighters and a reliable water supply, while the lack of such services must be assumed in survival shelter construction (Murphy, Rempel, and Beck, 1975).

3. NUCLEAR WEAPON EFFECTS

This review is principally concerned with shelter against the effects of nuclear weapons. The vast literature on shelter was largely stimulated by the nuclear development program in the United States. In order to adequately discuss shelter, a brief review of the most important effects of nuclear weapons which have a bearing on the design of shelter is required. The following discussion of such effects is based on information taken from The Effects of Nuclear Weapons (Glasstone and Dolan, 1977). The information contained in this volume is based on extensive U.S. weapons tests in the 1950s and early 1960s. The Effects of Nuclear Weapons is universally recognized as the authoritative source on all weapons effects. For other background information on the effects of nuclear weapons, the following references are suggested: Brode (1968); Jordan (1984); Jordan and Welsh (1984); Sartori (1983); and U.S. Department of the Army (1984a). A more specific discussion of weapons effects as they relate to structures is contained in: Brode (1964); Heierli and Jundt (1982); Mitchell (1961); Wiehle and Durbin (1966).

The only information on the direct effects of nuclear weapons on populated cities comes from the atomic bombings of Japan during World War II. These effects, both upon structures and upon people, are described in: Davis, Baker, and Summers (1966a, 1966b); Manhattan Engineer District (1946); Committee for the Compilation of Materials on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki (1981); Mixter (1967); U.S. Strategic Bombing Survey (1946, May 1947, June 1947); White, Bowen, and Richmond (March 1964, August 1964).

3.1 BLAST

When a nuclear weapon explodes, a high-pressure wall of air (the "blast wave") is driven away from the point of the explosion. The blast wave travels faster than the speed of sound in air; its effect at some distance from the explosion will not be observed for several seconds after the nuclear detonation has occurred. The pressure of this blast wave (the "overpressure") decays as the wave travels away from the explosion; nevertheless, the blast wave will flatten structures in its path if they haven't been constructed with sufficient strength. This mass destruction of property is the usual effect desired from the military use of nuclear weapons; it determines the choice of weapon size, burst height, and aiming point.

Blast protection is so central to shelter design that it is useful to express the location of other weapon effects in terms of the corresponding blast wave overpressure rather than in terms of the distance from the explosion. This has been done extensively in this report.

Figures 3.1 and 3.2 give the overpressure as a function of distance from various-sized weapons for airbursts and for groundbursts. The airbursts in these figures were assumed to occur at that altitude which subjects the largest possible area to the specified blast overpressure; this is called an "optimum height--of-burst" explosion.

The blast wave is accompanied by a high wind. For example, a blast wave with a 50-psi overpressure (3.3 atmospheres) is accompanied by a 1000 mph wind (1600 km/hr). Even a 5-psi overpressure (0.3 atmospheres) is accompanied by a 160-mph peak wind. This high-velocity wind is responsible for much of the destructive effect of nuclear weapons on aboveground, drag sensitive structures, such as ordinary frame houses. The high wind can also blow building debris into hardened structures,such as shelter air intakes, thereby producing a much more destructive effect than the wind alone. In a built-up environment, the presence of such debris must be taken into account when designing those portions of a shelter which extend into the open air.

When the blast wave strikes a flat surface directly in its path (that is, when it strikes it head-on), a reflected overpressure is produced as the result of an almost total stoppage of the airflow. This reflected overpressure can increase to a value up to 8 times as large as the overpressure of the incident blast wave. The effect of this pressure amplification upon surfaces can be catastrophic. For example, a 100-psi (6.9-atmosphere) shockwave reflected from a flat surface will momentarily produce a pressure on the surface of 500 psi (34 atmospheres.)

If the blast enters what is called a "re-entrant corner" (for example, where a vertical wall meets a horizontal surface) the incident overpressure can be amplified by a factor of 10 or more with a corresponding increase in destructive effect (Dresner, 1969). The phenomenon can be very troublesome in the design of entrances, particularly if a surface entrance employing a vertical door is desired.

Another consequence of the motion of the air associated with a blast wave is the "negative phase." After the blast wave has passed there will be a reverse flow of the wind, and for a short time the pressure will drop below normal by about two-tenths of an atmosphere (3 psi). This negative pressure is usually negligible compared to the initial blast overpressure; however, it will produce forces in the opposite direction for which the structure is normally designed. These are the forces for which hinges and blast door latches must be designed. A negative pressure of 3 psi can lift a 3-ft-thick slab of concrete if it is not securely anchored.

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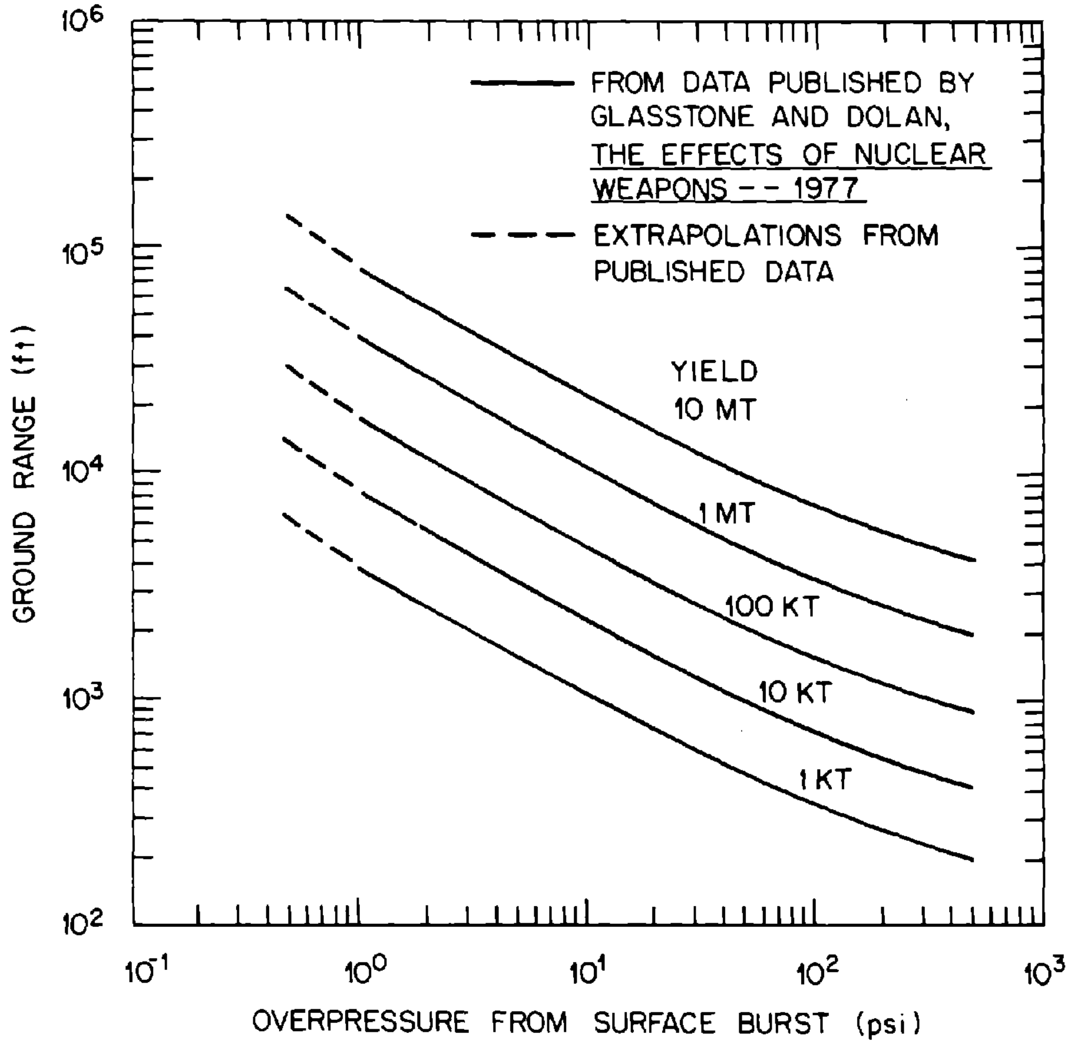

Fig. 3.1. Weapon overpressure as a function of distance from a surface burst.

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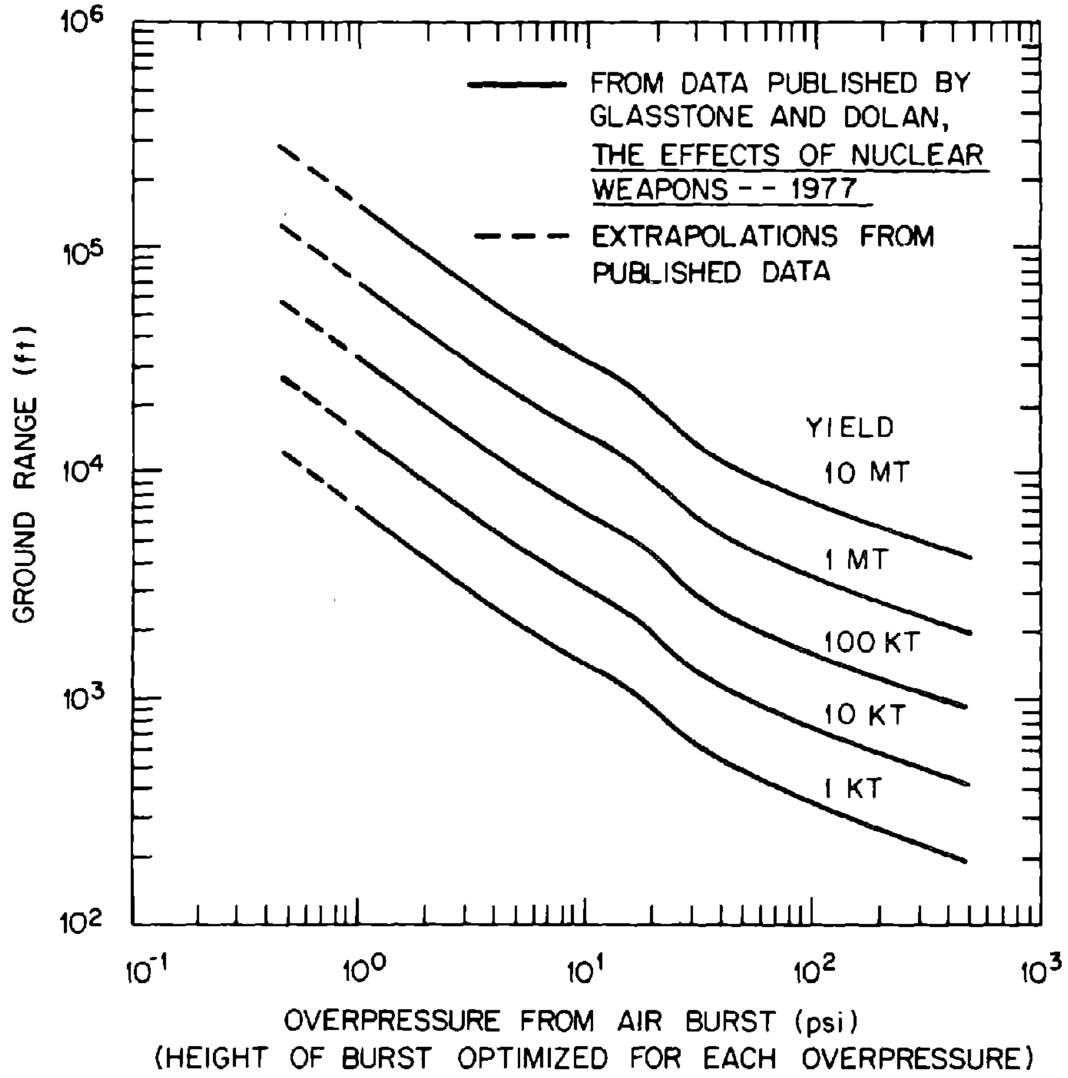

Fig. 3.2. Weapon overpressure as a function of distance from the ground zero of an airburst.

For additional information on blast effects, the following references are suggested: Avise (1971); Brode (1980); Brotherson, Wright, and Pecora (1968); Crowley et al. (1968); Federal Emergency Management Agency (May 1982b); Hickman and Meier (1983); Hobbs and Wetmore (1980); Longinow (1980); Longinow, Guralnick, and Mohammadi (1982); Longinow, Hahn, Wiedermann, and Citki (1974); Longinow, Watermann, and Napadensky (1982); Longinow, Watermann, and Takata (1982); Pickering and Bockholt (1971); Pinkston (1964); Richmond, Damon, Bowen, Fletcher and White (1966); Richmond, Fletcher and Jones (1971); Schmidt (1971); T.Y. Lin and Associates (1964a, 1964b); Wiehle (1974).

3.1.1 Shock Filling of Shelter

The high pressure air in a blast wave will flow violently into any shelter opening. Casualties can be produced in the shelter by the jet of air, often accompanied by wind-borne debris, which enters the door even though the structure itself is not damaged by the blast overpressure. This phenomenon has been extensively studied by Coulter and his associates at Ballistic Research Laboratories (Coulter, 1969, 1970, 1971, 1972, 1974, 1975, 1976; Kucher and Harrison, 1977).

For additional information on blast filling in shelter and the consequences for shelter occupants, the following references are suggested: Childers, Vansant, and Mokrauer (October 1968); Chilton (1958); Duff and Hollyer (1950); Ingram (1963); Kriebel (1972); Longinow, Hahn, Wiedermann, and Citki (1974); Melichar (1968, January 1969, November 1969, 1970); Pinkston (1964); White et al. (1956).

3.1.2 Risk Areas

The present Soviet arsenal is large enough to attack all strategically important targets in the United States. Figure 3.3 shows a map of the area which could be covered with 2 psi or greater blast overpressure in one hypothetical, very large-scale (1444 weapons, 6559 megatons) attack (Haaland, Chester, and Wigner, 1976). Other assessments of the risk areas from a large-scale nuclear exchange have been presented by the Defense Civil Preparedness Agency (1975) and by Sager, Hulbert, and Sullivan (1979). Blast shelters would be required for the survival of the population in those risk areas which could not be evacuated before the attack. Fallout shelters would be required for the balance of the U.S. population (see Section 3.7).

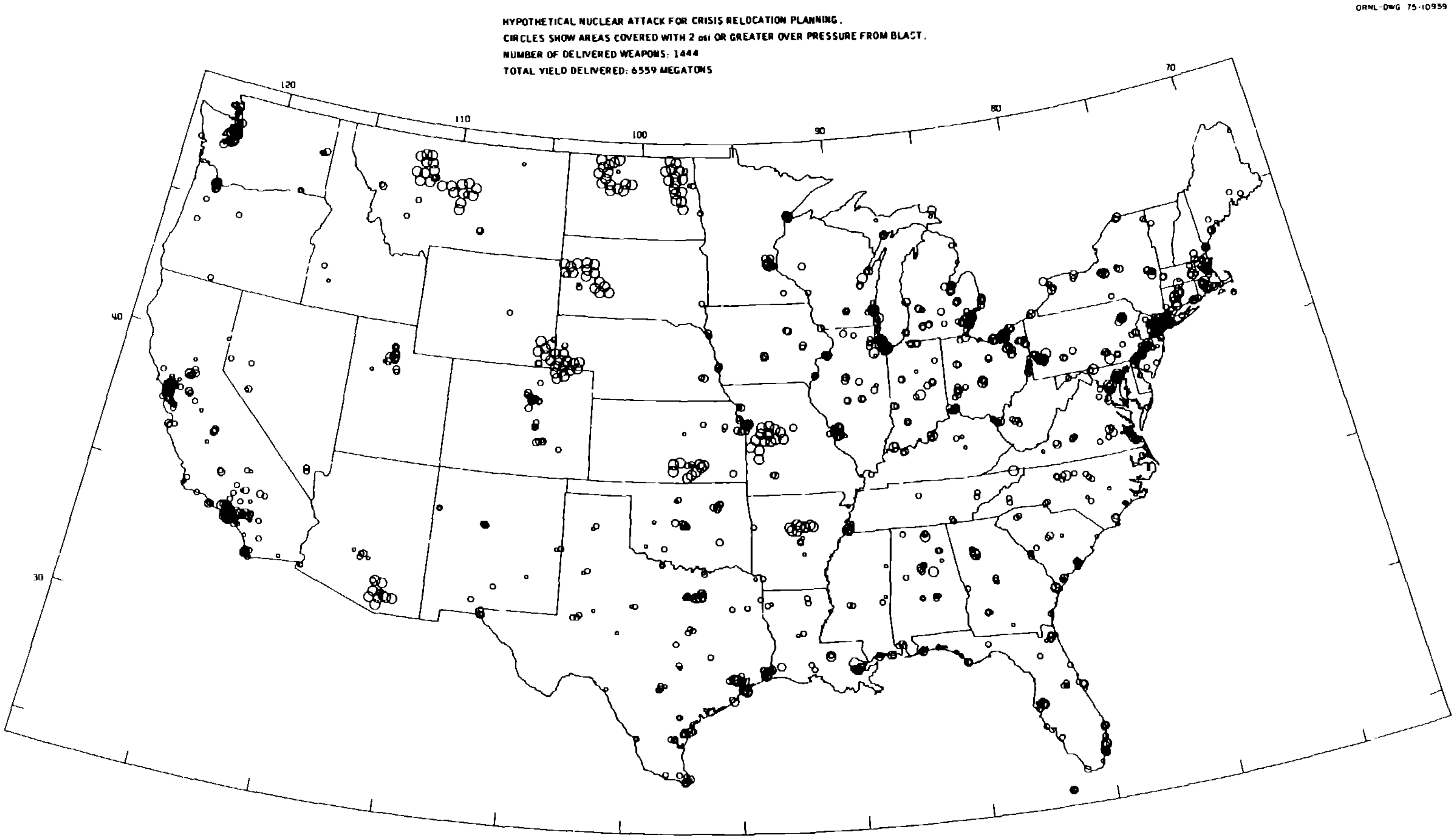

Fig. 3.3. Hypothetical attack pattern on the United States.

3.2 INITIAL NUCLEAR RADIATION

Initial nuclear radiation is that neutron and gamma radiation which is emitted by a nuclear weapon within one minute of its detonation. The source of the neutron radiation is principally the fission or fusion reactions occurring in the weapon, including delayed neutrons emitted by some fission products. The source of gamma radiation is the fission reaction, decay of fission products, inelastic collision of neutrons,and neutron capture reactions, particularly those with nitrogen in the atmosphere and within the shelter structure. Initial nuclear radiation is attenuated by the atmosphere and is of little consequence from large-yield (megaton-range) weapons at low overpressures. It begins to become an important consideration in shelter design at overpressures above 30 psi and for weapon yields in the range a few tens of kilotons to a few hundred kilotons (See Fig. 3.4 and 3.5). For shallow-buried structures designed to resist 30 to 50 psi from weapons up to 300 kT, initial nuclear radiation determines the thickness of the roof slab and the design of the entrance more than does the required resistance to blast overpressure.

The production of initial nuclear radiation is well understood, as is its interaction with matter and shielding geometries. The actual radiation which would be experienced in a nuclear attack depends on weapon yield and weapon design, varying by as much as a factor of 5 for a given yield.

The trend toward smaller weapons, the use of multiple warheads on intercontinental ballistic missiles, and the advent of small-yield cruise missiles will make initial nuclear radiation a more important design consideration in the future. Gasten (1980) has shown that initial nuclear radiation from small warheads in a large-scale attack on a city can significantly increase the casualties, if there is inadequate protection against it. Design for initial nuclear radiation would be very important in shelter for critical workers in high-risk areas.

For additional information on initial nuclear radiation, the following references are suggested: Abbott (1973); Albert, Huszar and Simmons (1977); Auxier, Burson, French, Haywood, Mooney and Straker (1972); Federal Emergency Management Agency (October 1980); French and Mooney (1972).

3.3 GROUND MOTION

If a nuclear weapon explodes near the ground (that is, a low airburst), then the high blast overpressures will cause the surface of the ground to move downward abruptly, the magnitude and speed being a function of the overpressure and its duration and

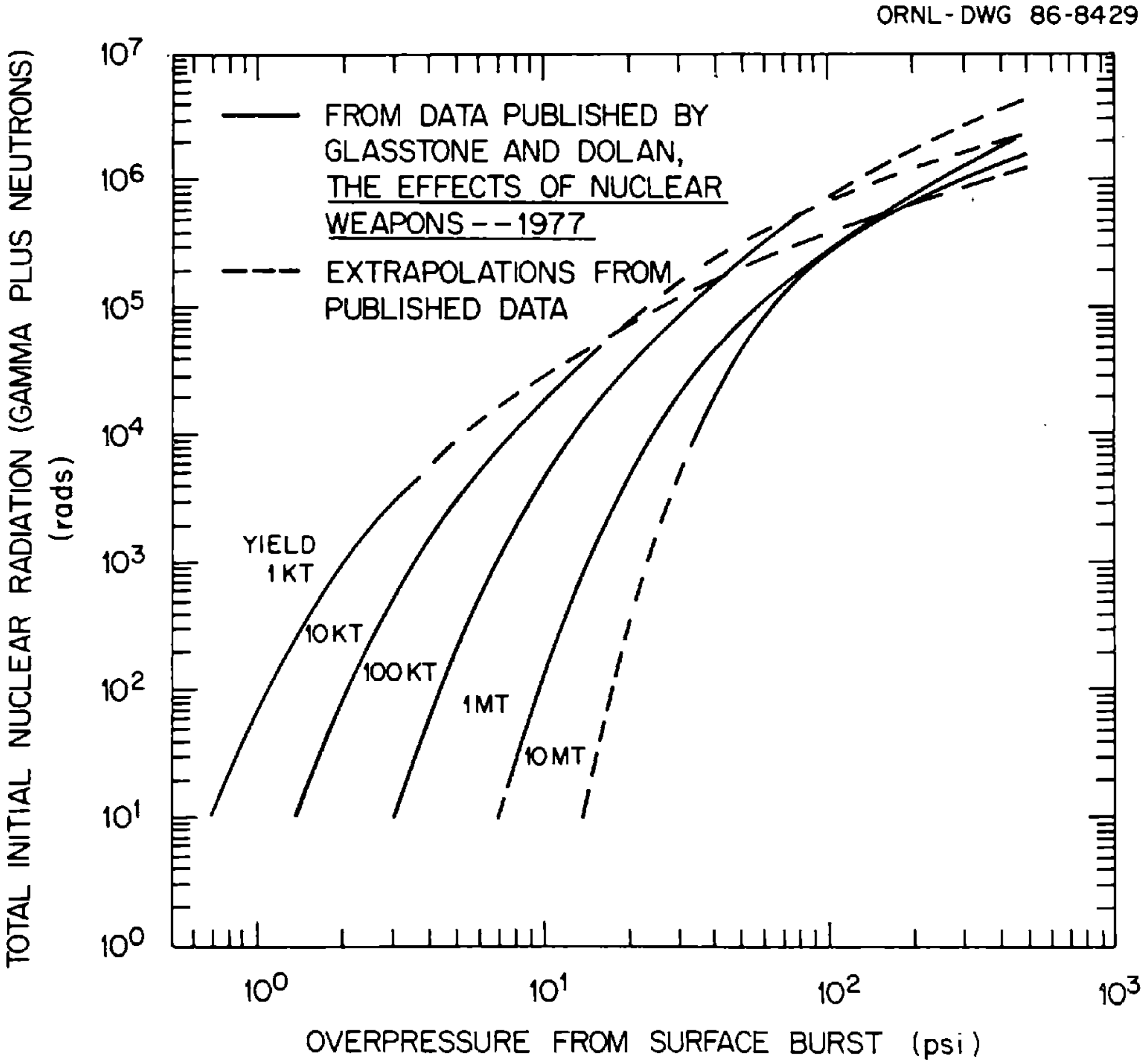

Fig. 3.4. Initial nuclear radiation as a function of overpressure from a surface burst.

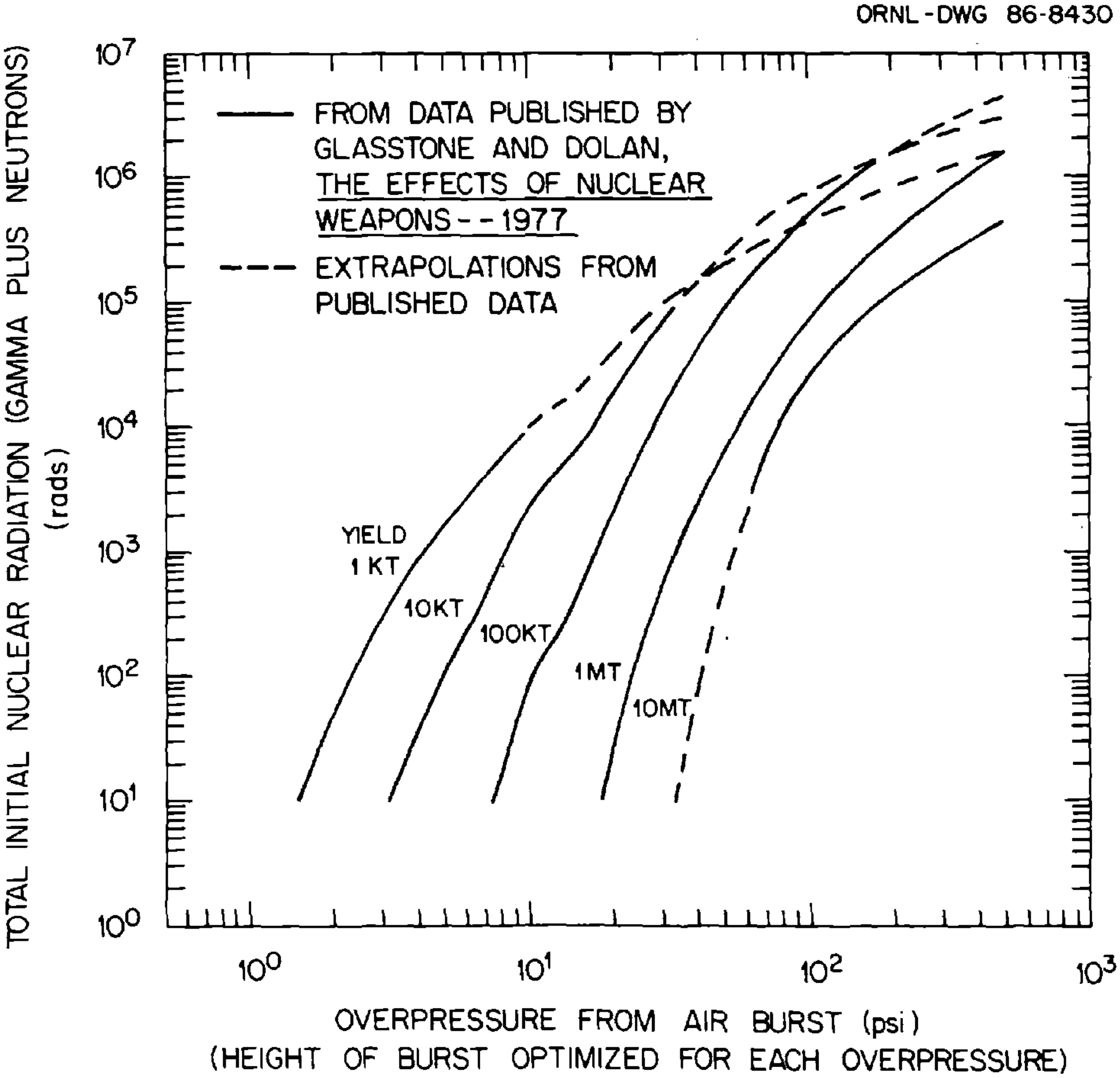

Fig. 3.5. Initial nuclear radiation as a function of overpressure from an airburst.

the nature of the soil. If the weapon is in contact with the surface (that is, a surface burst), some of the blast energy is transmitted directly into the ground, and produces compression and shear motions which propagate radially outward from the explosion. At close-in ranges the ground-transmitted shock arrives after the air-slap or air-induced ground motion. At greater distances the ground-transmitted motion often arrives first. The exact circumstances depend on the seismic velocity of the earth (soil and rock layers) at the general location. Since there can be several layers in the earth with different seismic velocities, the motion can be quite complex.

At very high overpressures (hundreds of psi), ground motions can be several feet in amplitude requiring careful consideration of shock isolation apparatus inside shelters. Care is required to provide the necessary "rattle space" in the shelter. This is a major concern in military command posts and missile silos designed for the high-overpressure regions.

For civilian shelters, ground motion is a minor problem unless a person is standing on a concrete floor; legs could be broken by the ground motion which accompanies overpressures greater than 75 psi. During the high accelerations which accompany large ground motions, heads could be badly injured if they are near a ceiling or a wall. Rempel (1967) reviewed the subject extensively and concluded that the problem was minor below 50 psi, except for people losing their balance.

Ullrich (1978) has presented a review of ground motion estimates. For additional information on ground motion and shock isolation, the following references are suggested: Amman and Whitney (1963); Collins, Daniels, and Overbeck (1978); Daniels (1979); Davis (1965); Hadala (1973); Jackson (1982); Lipner, Anderson, and Dai (1975); Merritt and Newmark (1964); Morrison (1964); Murphy (1967); Murphy, Shaw, and Tzeng (1982); Perret (1960); Sevin, Shenkman, and Welch (1961).

3.4 THERMAL EFFECTS

A nuclear weapon exploded in the lower atmosphere will produce approximately 35% of its energy as thermal radiation. While this energy can ignite combustible materials to about 20 miles away from a large-yield explosion, it is generally not a major design consideration for underground shelters (Davis, Miller, Ely, Basso, and Pearse, 1959).

The most important consideration of thermal radiation for shelter design is the consequence of igniting the contents of a building through windows and setting the building on fire. This has grave implications for the design of shelters in building basements; while the basement shelters may not burn, the contents of the building above them might, thereby producing heat, smoke, and toxic fumes which might endanger shelter occupants.

Figure 3.6 shows the thermal energy from a range of weapon sizes which would be incident upon various overpressure locations on a clear day. Even at overpressures as low as 10 psi, from intermediate yield weapons, the thermal fluence (cal/cm^2) is enough to ignite most combustible materials.

At locations exposed to a high thermal fluence, metal blast doors and ventilation intakes/outlets at the surface may be sufficiently heated by the thermal radiation before the arrival of a blast wave to lose significant amounts of their strength. The weakened metal may not permit the blast door or ventilation intake to develop its design resistance to the subsequent air blast and may even result in failure.

3.5 FIRE

Nuclear weapons can be considered incendiary weapons over much of the area they affect. Figure 3.6 shows that easily ignitable, dry materials can be ignited at overpressures as low as 2 to 3 psi, resulting in fires (from a 1 MT surfaceburst) to about 4 to 5 miles from a surface burst. From a 1 MT airburst, this maximum ignition distance is 6 to 8 miles. In addition to the thermal pulse igniting combustible material, the blast wave itself can initiate fires by overturning furnaces, stoves, and heaters, and by producing electrical short circuits and broken gas lines.

The fire problem is a complication in the design of shelters in highly built-up areas. Burning debris can complicate the design of air intakes. In particular, fires and carbon monoxide production can be hazardous to a shelter in the basement of buildings unless very careful provision has been made to supply fresh air from far outside the building. Buildings that have large amounts of combustible material inside can collapse into basements.

Much has been made by opponents of civil defense of the deaths of people in basement shelters in Hamburg, Germany in World War II. It is often asserted that shelters would be converted to crematoria by firestorms. These assertions are based on ignorance or distortion of the facts surrounding the raids on Hamburg. Although over 40,000 people died in Hamburg, 85% of the population of the burned-out area survived, and no one was killed inside specially designed shelters ("bunkers") (see Section 1.5 and Earp, 1953). The fatalities came primarily from people in basements of multistory buildings, from bomb damage, and from being caught in the open by fire and smoke (Miller, 1972). However, there is ample evidence that the threat to basement shelters lacking adequate means of ventilation is from heat as well as from carbon

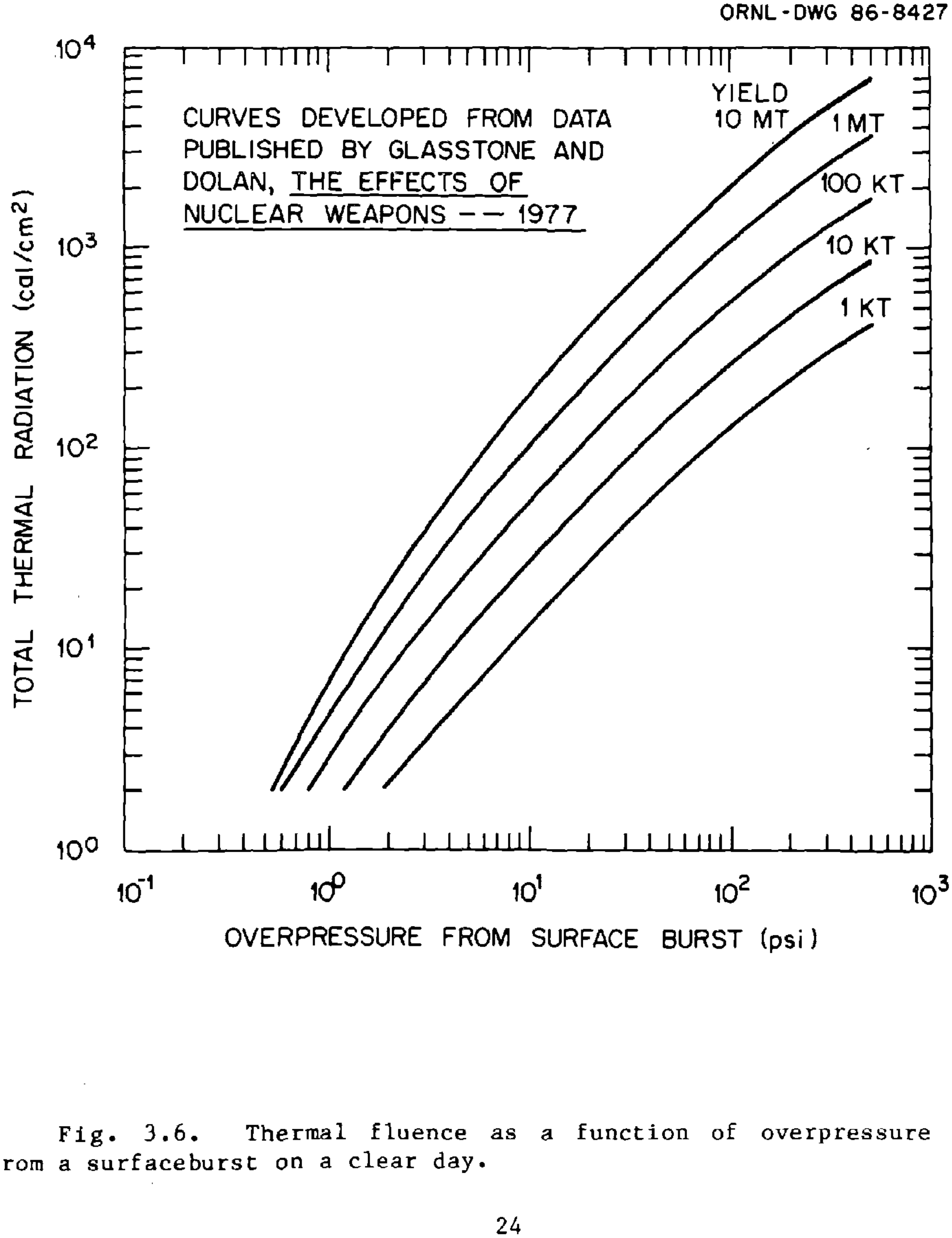

Fig. 3.6. Thermal fluence as a function of overpressure from a surfaceburst on a clear day.

monoxide and other toxic gases (Irving, 1964; Keller, 1966; Miller and Kerr, 1965; Murakoa, 1961; Vodvarka and Salzberg, 1969).

A great deal of fire research has been sponsored by the Federal Emergency Management Agency and its predecessors. However, most of it is only peripherally related to shelter other than to recognize that people could probably not survive in the vast majority of the designated fallout shelter spaces in the event that fire swept the area. Enough is known to permit confident designs of shelters which would protect their occupants against mass fires that were burning over them.

For additional information on fires as they relate to shelters and on the interaction of blast and fire, the following references are suggested: Avise (1971); Broido and McMasters (1960); Crowley et al. (1968); Goodale (1971a, 1971b); Hedge and Watermann (1969); Hickman and Meier (1983); Lee et al. (1966); Longinow, Waterman, and Napadensky (1982); Longinow, Waterman and Takata (1982); Smith, Cousins, and Newman (1964); Stubbs (1965); Takata and Waterman (1972); Waterman (1966, 1973,1974).

3.6 RUBBLE

In highly built-up areas, such as in high-rise districts in central cities, the potential generation of great depths of rubble complicates shelter design in these areas. The design of entranceways, emergency escape passages, and ventilation intakes must take into consideration the quantity and probable location of rubble after a nuclear attack. Rubble is one of the factors that makes the design of shelters in high-rise buildings very difficult (Bernard and Wilton, 1983). A good way of dealing with the rubble problem, aside from evacuating the built-up areas of the city, is the construction of rather long escape tunnels from shelters in or near buildings, out to open areas expected to be relatively free of rubble. Most cities, even though highly built up, will have occasional open areas in the form of major street intersections, parks, and parking lots (Bechtel Corporation, 1967; Haaland, 1970).

A great deal of work has been done on the movement of building debris including that by Coulter (1978); Bernard and Wilton (1983); Heugel and Feinstein (1967); and Longinow, Widermann, Citko, and Iwankiw (1976).

There has been a lot of research done on the formation and propagation of debris from buildings. Much of this has been directed toward predicting debris depths in streets as an obstacle to re-entry into the area and as a contributor to the fire hazard. It was recognized early (Rotz, 1967), that ordinary commercial buildings are converted to debris somewhere above 10 to 12 psi, depending slightly on yield.

Much effort has been made to develop codes to predict debris formation and other codes to predict debris trajectories (Rempel, 1980). While building breakup is reasonably well understood, debris trajectories are not, with the existing codes tending to overestimate the travel distances. Debris depths are estimated by assuming travel lengths which are sufficiently long with respect to variation in building density to provide a uniform layer of rubble (Longinow, Kalinowski, Kot, and Salzberg, 1970). This depth can be a few tenths of a foot in suburban residential areas, ranging to several tens of feet in dense high-rise areas in the centers of major cities.

At overpressures under 15 psi, and especially in the neighborhood of 5 to 10 psi, building rubble is not scattered but is deposited downwind of the building in a space not much larger than the height of the building. This possibility must be kept in mind when specifying the location and entrances of shelters for individual residences or multifamily residences in suburban areas.

3.7 FALLOUT

When a nuclear weapon explodes sufficiently close to the ground, particles of soil and debris are drawn up into the fireball and subsequent cloud, where fission products from the weapon are deposited in and upon them. These contaminated particles settle by gravity out of the atmosphere at a rate depending on their size and weight, the height to which they were raised, and the wind speed. The majority of particles settle out in 24 hours, but very fine particles falling from extreme altitudes can settle out weeks, months, or even years later. These late-arriving particles represent but a very minor hazard to health, because the radiation dose rate from fallout quickly decays. Compared to the reference dose rate one hour after an attack, the dose rate decays to 1% in about two days, to 0.1% in about two weeks, and to 0.01% (1/10,000th) in about three months. The danger is principally from the fallout arriving within the first day or two after the explosion.

In terms of the population put at risk or the area covered, radioactive fallout is by far the most important effect of ground-burst nuclear weapons. An attack consisting of several thousand ground-burst megatons can cover virtually all of the United States with lethal fallout (see Fig. 3.7). (An accumulated dose of about 450R will produce fatalities in approximately 50% of the exposed population.) In an actual attack, there would be some areas that would not be covered at all by fallout and other areas that would be experience very high dose rates.

Haaland, Chester, and Wigner (1976) have evaluated the quantitative threat to the U.S. population from an attack of 6559

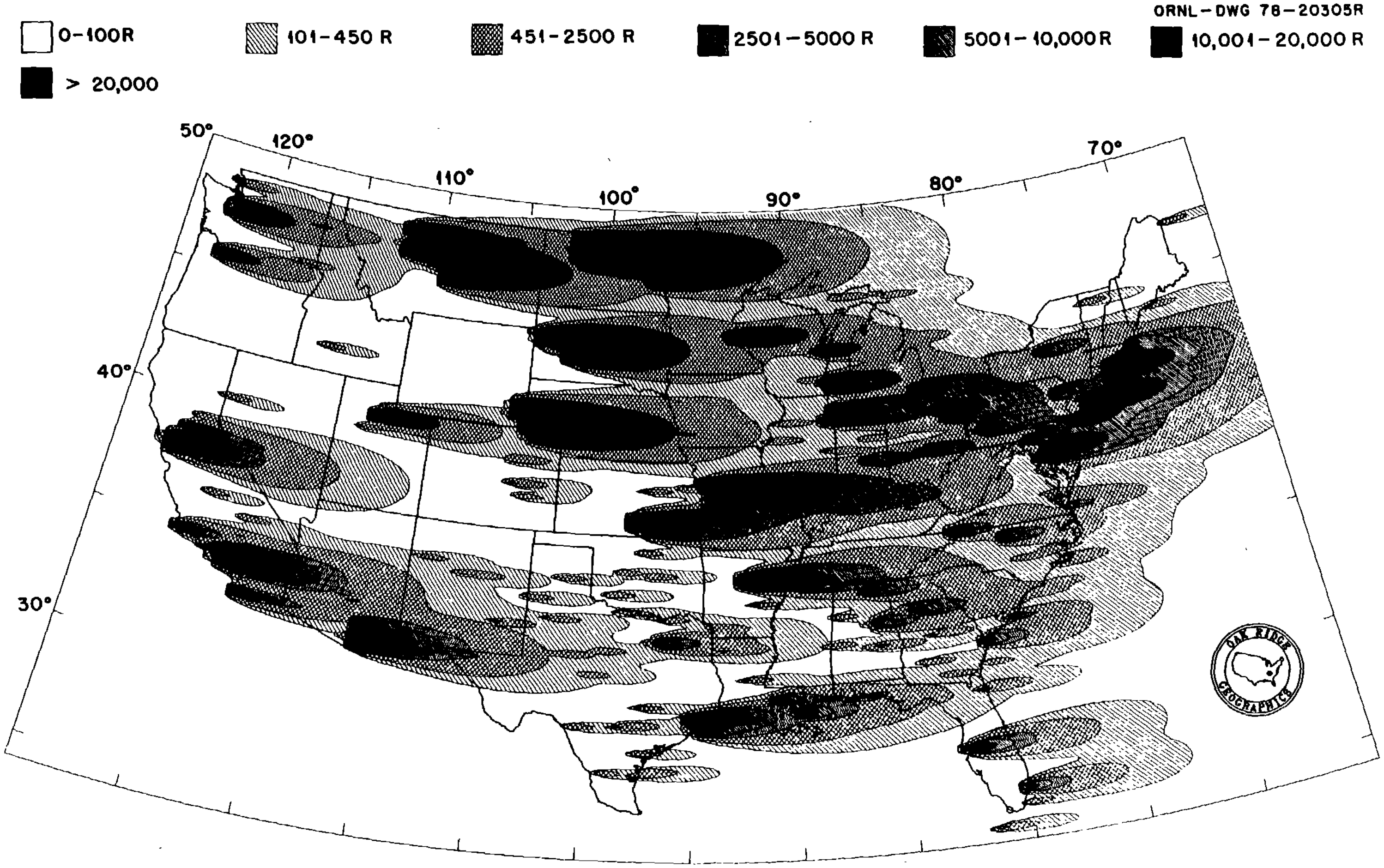

Fig. 3.7. Accumulated 14-day fallout dose patterns from a hypothetical attack on the United States.

megatons, most of which are ground-burst. In this scenario, over 80% of the U.S. population would be in danger of receiving lethal doses from fallout radiation unless some protective action had been taken. Figure 3.8 is a graph of the unit-time reference dose rate to which the population would be exposed versus the fraction of population exposed to that dose rate or greater. In many cases, the dose accumulated over a few days will be numerically equal to three times the reference dose rate. For example, a reference dose rate of 160 R/hr will result in an accumulated dose of about 500R in a few days (for details, see Haaland, Chester, and Wigner, 1976).

Prediction of exact fallout patterns prior to an attack is impossible, since the fallout depends on wind directions at the time of attack. Schmidt (1981) has demonstrated this by the calculation of 12 fallout patterns representative of weather conditions in each of the 12 months of a particular year.

Research on fallout has been accorded the attention and resources that it deserves and is sufficiently well understood for any practical civil defense program. A fallout shelter is needed everywhere outside the areas exposed to the risk of blast. Moderate radiation protection would save nearly everyone and would significantly reduce the amount of injury from fallout radiation as well as increase the tolerance of the surviving population for any subsequent radiation exposure acquired during cleanup.

The fallout phenomenon has been exceptionally well covered by the Federal Emergency Management Agency (June 1973a); Ferlic (1983); and Glasstone and Dolan (1977). For additional information on fallout, the following references are suggested: Burson (1963); French and Olmeno (1966); French, Price, and Tompkins (1968); Harvey and Serduke (1979); Lacayo and Sullivan (1967); Mather (1968); Miller (1958); Read (1967); Shumway and Frank (1968).

3.8 CLIMATOLOGICAL EFFECTS

In the past few years atmospheric scientists have raised the possibility that the explosion of large numbers of high- and intermediate-yield nuclear weapons could produce changes in the atmosphere. At the present time, two possible effects are of concern.

The first is the possibility that nitrogen oxides produced by the high temperatures in the nuclear fireballs will be carried into the stratosphere where they will react to deplete the ozone at those altitudes. The loss of the ozone would permit more of the short-wave ultraviolet radiation from the sun to penetrate to the surface of the earth, thus increasing the rate at which people could be sunburned as well as the long-term possibility of skin

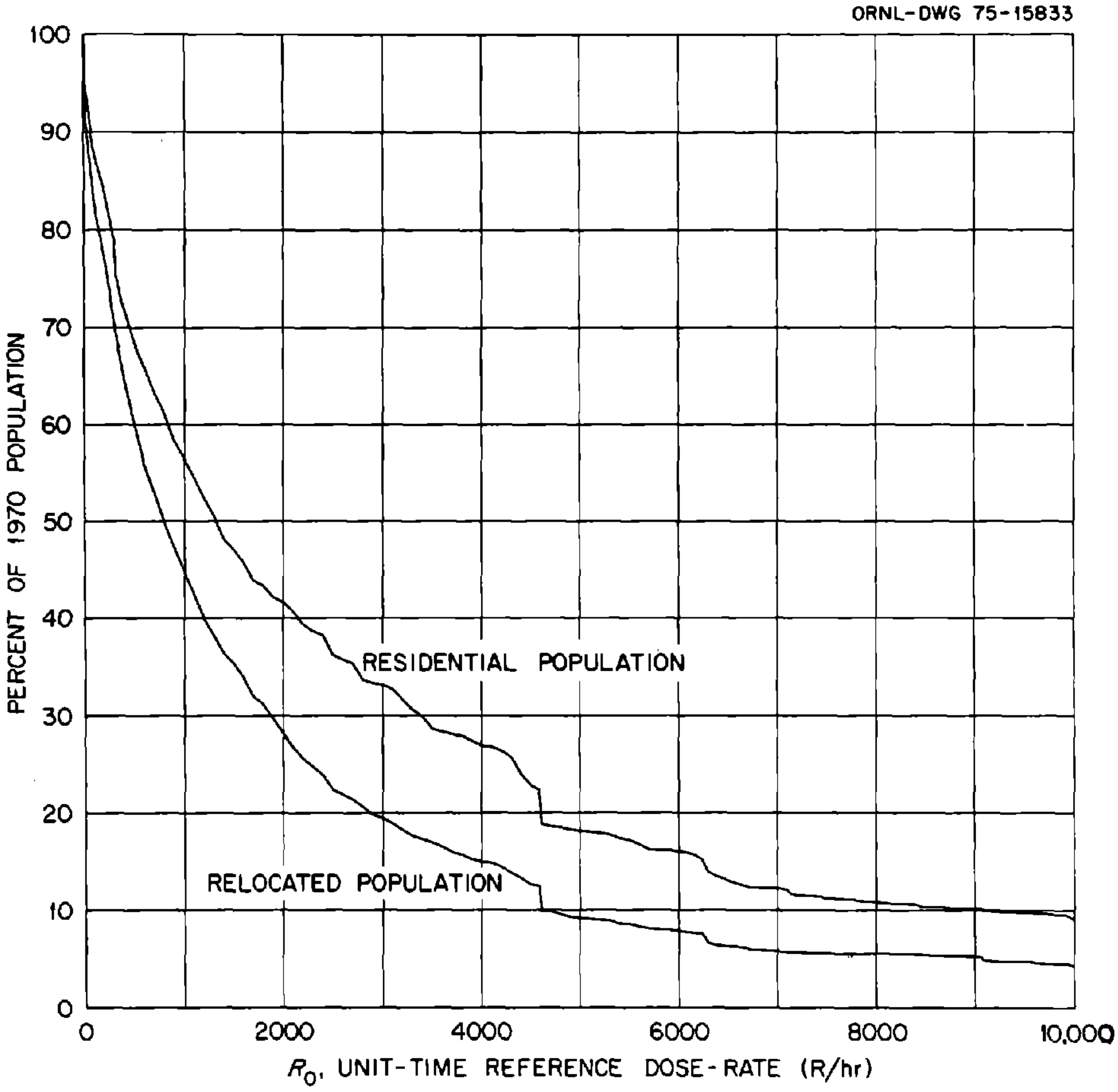

Fig. 3.8. Cumulative population exposed as a function of fallout radiation dose rate.

cancer. Increased ultraviolet radiation would be of little concern to anyone inside a shelter. If ozone depletion were severe enough, it might require people working in the open after the attack to wear hats, long-sleeved shirts, and gloves.

Some estimates of the potential for ozone depletion have gone as high as an 80% removal of the ozone layer, requiring many large-yield weapons to produce this effect. The trend toward lower-yield weapons is expected to dramatically reduce the potential effect on the ozone layer; the fireballs from intermediate-yield weapons do not rise high enough in the atmosphere to reach the main concentrations of ozone.

The second, and more acute, concern about the climatological effects of nuclear war is the possibility that millions of tons of smoke and dust might be injected into the atmosphere and might prevent sunlight from reaching the surface of the earth. This is the "nuclear winter" theory; it is postulated to cause a 20 to 30°C cooling of the earth's surface if the nuclear war occurs in summertime (National Research Council, 1985). There would be little cooling effect if the nuclear war occurred in the winter time.

The expected cooling in a spring or summer nuclear war could result in temperatures in the mid-latitudes of the northern hemisphere, characteristic of wintertime, but occurring in July or August. These temperatures would present no threat to people living in shelters especially if they had brought winter clothing with them.

The principal effect of nuclear winter would be the destruction of the summer crops in the mid-latitudes of the northern hemisphere. Loss of a crop year is not a new threat to either the United States or the Soviet Union, since both countries expect massive damage to agricultural productivity from fallout in the event of a nuclear war. Both countries have at least one year's supply of grain stored which will enable them to survive the loss of a crop year. In the Soviet Union the stored grain is in the form of state food reserves. In the United States it is in the form of unsold grain on farms or in commercial storage silos in farming areas.

Even without nuclear winter the disruption of grain production in the Soviet Union, Canada, and the United States could severely affect food-importing countries, resulting in famine in areas outside the warring nations. If, in addition, the postulated effects of smoke and dust in the atmosphere extend to low latitudes or even into the southern hemisphere as has been suggested by some, the result could be a severe famine in those countries which do not produce large food surpluses.

Nuclear winter does not present any new, qualitative problems for Soviet and U.S. civil defense programs. There are already a number of difficulties for the surviving population in those countries. It would require that careful attention be given to nationwide planning and management of food reserves. It would make it advisable that any nationwide shelter program be accompanied by a carefully planned food storage and food distribution program if the shelter program is to have credibility.

4. SHELTER DESIGN COMPONENTS

The technology for designing shelters to protect people against combined nuclear weapon effects has been steadily maturing since the 1950s. One approach to shelter design is to consider each component of the shelter in terms of the weapon effect that it protects against; however, there are important synergisms. For example, some things done to improve radiation protection (e.g., thicker concrete or deeper burial) will also improve the protection against blast overpressure.

Many design studies, guide books, and manuals have been written to provide information on shelter component design. The American Society of Civil Engineers' Manual No. 42 (ASCE 1985), Design of Structures to Resist Nuclear Weapon Effects, 1985 edition, was found to be most authoritative, up-to-date, and complete. This manual should be obtained by anyone faced with the task of designing a blast shelter.

The following references include other aspects of the problem and are suggested for the interested reader: Albright (1961); American Society of Civil Engineers (1985); Ammann and Whitney (April 1965); Anderson et al. (1961); Callahan, Rosenblum, and Coombe (1961); Crawford, Higgins, and Bultman (1974); Defense Civil Preparedness Agency (November 1972b, February 1976, November 1976, February 1978); Federal Emergency Management Agency (1979, January 1980a, September 1980, 1981, August 1982, October 1982, January 1985, March 1985); Finlayson, Fugelso, and Shulman (1965); Holmes and Narver, Inc. (1965b); Home Office and the Central Office of Information (1982); Huddleston, Doty, and Ingold (1968); Merritt and Newmark (1958); Newmark (1956); Newmark and Haltiwanger (1962); Nordell (1969); Office of Civil Defense (August 1962b, August 1962c, November 1962a, November 1962b, 1968, January 1969); Ormerod (1983); Oster (1985b); Sibley (September/October 1984); U.S. Army Corps of Engineers (1946, 1957a, 1957b, 1957c, January 1958, 1959, July 1959, January 1960a,January 1960b, January 1960c, January 1961, April 1961); U.S. Army Engineer School (no date); U.S. Department of the Army (October 1983a, October 1983b, December 1983, June 1984, July 1984a, July 1984b, August 1984); U.S. Department of the Navy (1961); Williamson (1960).

4.1 OVERPRESSURE PROTECTION

Blast overpressure is usually the most important weapon effect to be considered in shelter design. Most shelters for civilians can be divided into one of two classes of approach to this problem. The first approach is to construct a building or building component which is strong enough to directly resist the

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blast overpressure. The construction material of choice is usually reinforced concrete. Examples are hardened basements and shallow-buried reinforced concrete structures. The second approach is to construct a yielding structure which is relatively weak with respect to high overpressure blast resistance (for example corrugated metal culvert) and to bury it deep enough in a granular, unsaturated soil so that the soil attenuates the blast load.

4.1.1 Strong Buildings

Shelter is most economically produced when it is an integral component of a new building; usually a basement location is chosen. Such shelters can be constructed out of concrete in the form of a rectangle, pipe, arch, or dome. Arches and domes have been considered for shelter for civilians but are generally not economical solutions due to their forming costs (Behr and Kiesling, 1985).

To protect against initial nuclear radiation at pressures greater than one atmosphere from intermediate-yield weapons, a barrier of concrete 3 or more feet thick or a layer of earth 4 or more feet thick is required. This concrete or earth inherently provides high overpressure protection. Usually above one atmosphere the design of the structure will be dominated by protection against initial nuclear radiation rather than overpressure.

The dynamic effects of the blast load should also be considered in protective structure design. Dynamic loads double the effective stress in those structures which remain in their elastic response range (such as most reinforced concrete members). If a load is abruptly applied to a structure and that load has a duration which is long compared to the natural frequency of the structure, then the structure will distort twice as much as if the load had been applied gradually. Hence, a structure which is to be designed for a-50 psi blast overpressure must be designed to withstand a 100-psi static load, if it is to remain in the elastic response range under long duration loading. Should the overpressure be large enough to deform the structure into its plastic range, then the structure will support a blast load at least equal to the static load for which it was designed (Denton 1967; Guice and Kiger, 1984).

If a load is applied to a structure for a duration which is short compared to the natural frequency of the structure and that load is in the elastic range for the structure, then the structure will first deform and then vibrate back through its original position, damping out quickly. Stresses which are equal in magnitude to those produced by the load but in the opposite direction will be developed in the structure. This reverse stress is called "rebound." The present "rule-of-thumb" in design is to assume that the rebound load is one-half of the incident peak load. Rebound is not usually an important consideration for nuclear weapons, which have blast overpressure durations that are very long compared with the natural frequencies of most reinforced concrete structures. It is of more importance to the military designer who is designing to resist the blast effects of conventional high explosive weapons.

For reinforced concrete slabs, which may be used for shelter walls, floors, and roofs, the slab thickness and its reinforcement (steel bar size, number of bars, and bar placement) are the principal design parameters. These parameters are determined from consideration of the bending moments which are expected within the slab as it resists the design overpressure. Accurate determination of the maximum expected bending moment is essential in selecting the proper amount of structural material which will provide the necessary resistance; this, in turn, directly influences the cost of such structures.

Since it is desired that the reinforced concrete slab not fail, theories of failure may be used to design such slabs. Several different failure theories may be used (Park and Gamble, 1980). The simplest design procedure assumes that the slab acts as a one-way member; its two-dimensional behavior is neglected. The requirements for the slab thickness and steel reinforcement are based on the bending moments developed in the short span of the slab.

Yield-line theory (Hognestad, 1953) takes two-way behavior into account.For a uniformly loaded, square slab which is simply supported (i.e., one which is not rigidly restrained at its edges), yield-line theory predicts approximately one-third the maximum bending moment as that from one-way considerations. Furthermore, designing a concrete structure so that the roof slab is rigidly connected to the walls reduces the bending moment at the center of the slab even further below that of a simply supported slab.

Recently, additional mechanisms have been discovered to provide increased flexural capacity in reinforced concrete slabs. These mechanisms seem to be explained by the compressive-membrane theory (Kiger, Eagles, and Baylot, 1984; Kiger, Slawson, and Hyde, 1984; Park and Gamble, 1980; Woodson, 1985; Woodson and Garner, 1985). The theory states that if the edges of the slab are restrained against lateral movement by stiff boundary elements, then in-plane (compressive membrane) forces are induced as the slab deflects. Changes of geometry then cause the slab edges to tend to move outward and to react against the bounding elements. These compressive membrane forces enhance the flexural strength of the slab. Compressive membrane action can increase the flexural capacity of rigidly supported slabs to 2 or 3 times that predicted by yield-line theory.

Obviously, substantial reductions in the design bending moment can be obtained by including the most complete failure theories in the design procedure. These reduced bending stresses can then be directly translated into reduced slab thicknesses and reduced requirements for the reinforcing steel within the slab, thus keeping the cost of the structure to a minimum.

Tunnels in rock can be considered a special case of strong buildings. Rock tunneling is very expensive per cubic foot of space produced. It is very unlikely to be used for civilian shelters unless the tunnel has been constructed for some other purpose, which will bear the cost of its construction, and then converted into a civilian shelter. Examples are limestone mines and vehicle tunnels. See Sections 7.4, 7.5.4, and 7.6.4 for additional discussion of tunnel shelters.

For additional information on the design of reinforced concrete structures and other strong buildings, the following references are suggested: Bagge (1972); Brotherson, Wright, and Pecora (1968); Brotchie, Jacobson, and Okubo (1965); Brown and Black (1973); Criswell (1970, 1972); Fedorkiw and Sozen (1968); Fiorato, Sozen, and Gamble (1970); Flathau, Sager, and Luzi (1962); Gabrielsen, Cuzner, Hendricks, and Zsutty (1982); Gabrielsen, Wilton, and Kaplan (1975); Giorlami, Sozen, Gamble, and Flug (1970); Havers (1963); Hobbs and Wetmore (1980);Huff (1975); Lamb and Dembo (1967); Longinow and Widermann (1977); McVay (1981); Peterson, Bernard, Tansley, Willoughby, and Wilton (1982); Romualoi and Ramey (1965); Schuman (1965); Selheimer (1971); Slawson, Taylor, Dallriva, and Kiger (1985); Wiehle and Bockholt (1973); Woodson (1984).

4.1.2 Yielding Structures and Earth Arching

Soils composed of discrete grains, such as sand or gravel, are said to possess the property of "dilatancy." This means that the individual soil particles normally interlock and that if a shear stress is applied to the soil then the soil must expand slightly if the grains are to ride over each other and move. When subjected to pressure these soils thus develop a significant shear strength. If a relatively flexible container is buried deep enough in such soil and the soil is subjected to pressure such as from blast overpressure, the container will deflect slightly (yield) and the load will be partially transferred to the soil. The soil is said to "arch" and partially carry the load around the container. The container can be a blast shelter made out of corrugated metal pipe, wood, or fiberglass, or even reinforced concrete. Buried concrete box structures also exhibit this same soil-structure interaction.

The earliest investigations into soil-structure interaction were conducted on the type of buried pipe and conduit used for drainage in railroad and highway construction. It was observed that flexible, buried conduit was capable of supporting loads well in excess of the loads which the same conduit could support in the unburied case. Iowa State College in cooperation with the U.S. Bureau of Public Roads demonstrated that flexible conduit and a compacted earth backfill acted as a complex, composite structure (Marston, 1930). From these early tests, simple theories of earth arching were developed.

During the 1950s many buried structures were designed, constructed, and tested as part of the U.S. nuclear weapons test program (See Section 5.1.1). The results of the knowledge gained in these tests and in laboratory simulations were presented at the Symposium on Soil-Structure Interaction in 1964 (University of Arizona, September 1964). Many static tests had been performed prior to this symposium; however, only in the last few years, has a well-instrumented set of dynamic field tests been conducted on buried structures (Getchell and Kiger, 1980, February 1981, December 1981; Kiger and Getchell, 1980, 1982; Kiger and Slawson, 1977; Slawson, Taylor, Dallriva, and Kiger, 1985).

The state of knowledge with respect to accurate design of buried structures is still evolving; however, recently proposed computational techniques (Kiger, Eagles, and Baylot, 1984; Kiger, Slawson, and Hyde, 1984) seem to account for the phenomena observed during earth arching. These techniques are summarized in useful form in the ASCE Manual No. 42, 1985 edition (American Society of Civil Engineers, 1985).

Experiments on flexible, buried tubes have shown the dramatic difference between a sandy backfill and a backfill of soft clay (Dorris, 1965). For tubes buried in sand (even for rather shallow depths of burial) the overpressure sufficient to cause failure is much greater than for a similar tube buried in clay. Granular, sandy soils develop considerable shear strength to resist the applied load. On the other hand, soft clayey soils lack sufficient strength to bear a significant portion of the load.

The "rule-of-thumb" which has resulted from such tests calls for the depth of earth cover above the structure to be not less than one-half of the minimum span of the structure. For buried cylinders, this depth equals one-half the diameter; for buried rectangular box structures, this depth is one-half the short span of the roof slab.

In order to take advantage of the increased load-carrying capability of buried structures due to earth arching, three elements must be present: (1) the structure must be buried in a granular soil at a depth equal to a significant fraction of the minimum span of the structure, (2) the structure itself must be flexible enough to yield under the applied load and, (3) the structure must not be located below the water table, and/or the surrounding soil must not be allowed to become water saturated. It is important for the structure to be flexible; the deflection of the structure under load allows the soil to redistribute itself into "arches" which are able to transfer the load away from the structure. A rigid, unyielding structure will tend to "attract" load; that is, the soil will transmit more load directly to the structure.

The earth arching phenomenon does not work in soils which are: (1) saturated or below the water table or (2) of nongranular character such as clay, peat, or silt. If the local soil does not have good properties for soil-arching, then an imported backfill of sand or crushed rock can be used around the shelter.

Shelters designed for blast overpressures of two to three atmospheres from small- or intermediate-yield weapons would require four to five feet of earth cover as shielding to protect the shelter occupants against initial nuclear radiation. For most reasonably-sized shelters, such protection against initial nuclear radiation also provides adequate cover to develop earth arching, provided that a suitable soil is used.

Allgood (1972) has produced the most complete discussion of the earth arching phenomenon, including a working calculational technique. Perhaps more useful is his observation for one-half span of earth cover employing granular soils: ". . . virtually any closed structure that will withstand the backfill stresses will resist 200 psi overpressure."

For additional information on earth arching, soil-structure interaction, and the blast resistance of buried structures, the following references are suggested: Albritton and Balasara (1980); Albritton, Kirtland, Kennedy, and Dorris (1966); Allgood, White, Swalley, and Gill (1963); American Iron and Steel Institute (1973); Canada and McVay (1985); DaDeppo and Werner (1962); Flathau and Balsara (1978); Harrenstein et al. (May 1965); Isenberg (1975); Isenberg, Wojcik, and Hikooyeh (1975); Jester (1970); Karagozian and Tsai (1979); Kennedy (1971); Kennedy and Ballard (1967); Luscher (1965, 1968); McNulty (1965); Mason (1965); Nakamo (1970); Palacious and Kennedy (1967); Schuman (1965); Thorne and Berglund (1968); Walker and Bultman (1984); Wiehle (1965); Williamson and Huff (1961); Wong and Weidlinger (1983).

4.1.3 Foundations

Blast loads applied to the roof of a shelter are transferred to the walls and through the foundations to the soil beneath the shelter. In soil with good bearing properties (dry, noncohesive), the dynamic bearing strength is very high. Under these circumstances, wall footings are often designed for an allowable static load.

Most blast tests on structures using nuclear weapons or large high-explosive blasts have been conducted in the United States in areas of dry soil with very good bearing strength. Many cities on the other hand are built near water on alluvial or filled soils containing large amounts of water over a shallow water table. Under earthquake conditions soils of this type have been observed to undergo liquefaction and lose all of their bearing strength. It has been suggested that similar effects could be produced by nuclear weapons (Mason and Walter, 1968; Edmunds, 1968; URS Research Company, 1970).

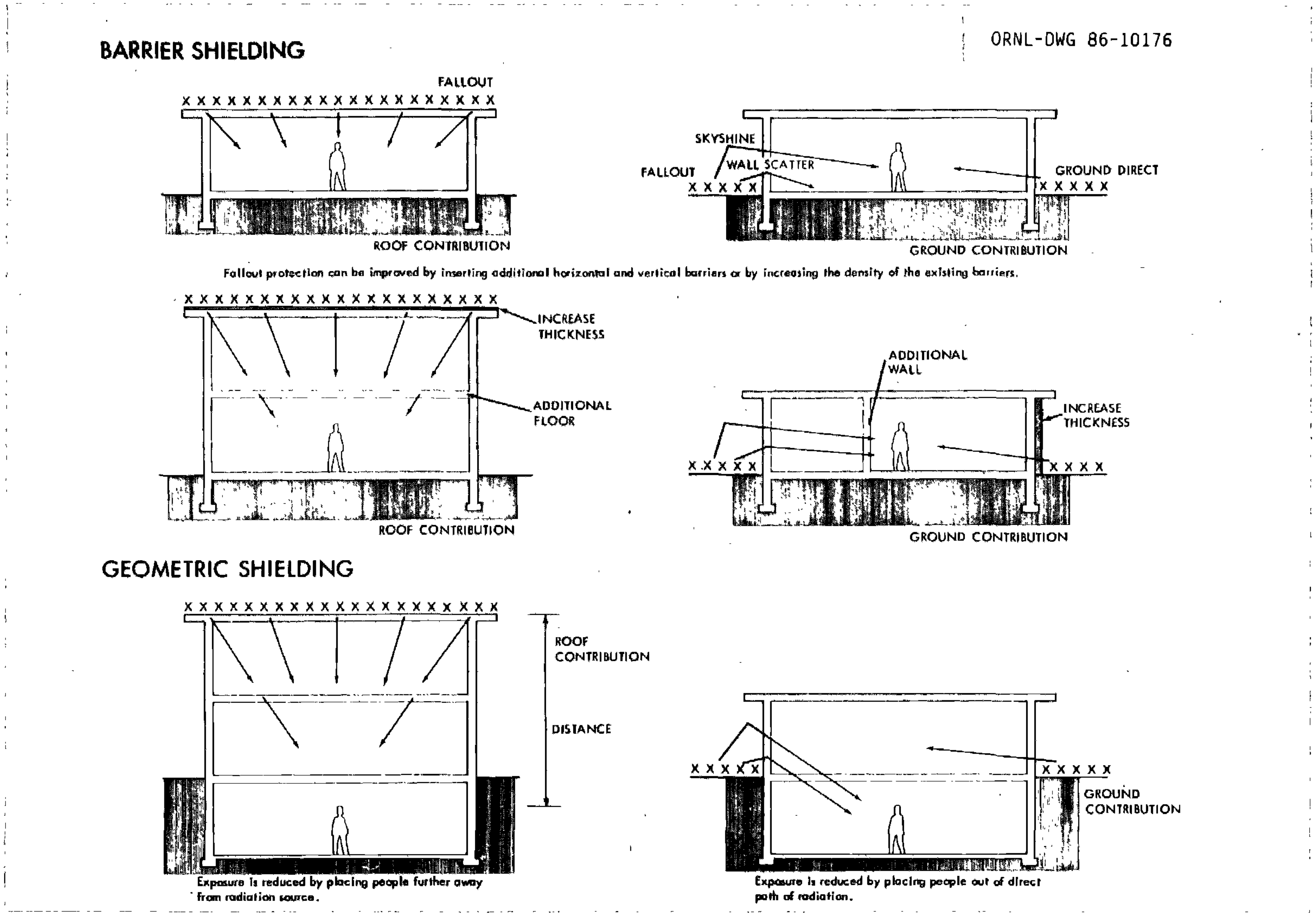
The solution to this problem is to support the walls of the building using the floor, designed as a mirror image of the roof, as a foundation (Anderson, et al., 1961). Using the floor as a spread footing is recommended procedure in any area where soils have poor bearing strengths. Conventionally designed footings can be used in soils of good bearing strength where there is absolute assurance that the soils are well drained.

4.2 RADIATION PROTECTION

Achieving adequate radiation protection is the major objective of fallout shelter construction. Blast shelters must also provide radiation protection in addition to blast protection. Radiation protection in fallout shelters is concerned only with fallout gamma radiation and not with the less-penetrating beta component of fallout radiation. Radiation protection in blast shelters is concerned primarily with initial nuclear radiation: the highly penetrating nitrogen capture gamma rays, fission product gamma rays, and neutrons. There are two methods of providing radiation protection: barrier shielding and geometry shielding, as illustrated in Fig. 4.1.

4.2.1 Barrier Shielding

The principle of radiation protection is to interpose mass and/or distance between the protected people and the source of the radiation. The mass can be any material: earth, concrete, steel, water, or even air(quite a large mass of air can be interposed between a person and a source of radiation when large distances are involved). A concise description of the interaction of radiation with shielding matter is given in Glasstone and Dolan (1977).



Fallout protection can be improved by inserting additional horizontal and vertical barriers or by increasing the density of the existing barriers.

Exposure is reduced by placing people further away from radiation source.

Exposure is reduced by placing people out of direct path of radiation.

Fig. 4.1. Barrier shielding and geometry shielding.

In providing shielding from fallout radiation, the decrease in radiation intensity is dependent upon the mass of material per unit area that intervenes between the source of the rays and the point of observation. The effectiveness of the material in attenuating gamma rays can be measured in two ways. The first measure involves the concept of "tenth-value thickness;" the second involves the "protection factor" concept.

A "tenth-value thickness" is defined as that thickness of the specified material which transmits a radiation dose (or dose rate) one-tenth of that which falls upon it. In other words, one tenth-value thickness of the material would decrease the radiation by a factor of ten. Each succeeding tenth-value thickness would bring about a further reduction by an additional factor of ten. For fallout gamma rays, the tenth-value thickness is approximately 8 in. of concrete or 12 in. of soil. These thicknesses can also be translated into the barrier's mass per square foot of exposed area; thus, any shield weighing about 100 lb/ft^2 would also have a thickness equivalent to one tenth-value thickness. A shield weighing about 200 lb/ft^2 (two tenth-value thicknesses) will reduce the radiation by a factor of 100, and 300 lb/ft^2 (three tenth-value thicknesses) will reduce the radiation by a factor of about 1000.

A "protection factor" (PF) or "fallout protection factor" (FPF) is that factor by which radiation intensity is decreased as it passes through a shield. One tenth-value thickness obviously provides a PF equal to 10. The protection factor concept can be applied to entire shelter structures, as well as individual barriers or shields. For fallout shelter design, the minimum recommended PF is 40 (which is about 1.6 times the tenth-value thickness). Either of these two measures of effectiveness can be used to describe the level of protection from fallout radiation.

For initial nuclear radiation, the situation is much more complicated involving the energy of the radiation, its interaction with the shield, scattering within the shield, and the shield's geometry. Figure 4.2 is a graph from Spencer (1975) showing the barrier attenuation of nitrogen capture gamma rays and fission product gamma rays from a simulated source of initial nuclear radiation as a function of the barrier thickness.

Table 4.1 is an application of Spencer's methods by J. O. Buchanan (reported in Strope et al., 1985) to a fully-buried basement with a concrete first floor of varying thickness. Doses from fission-product gamma rays, nitrogen capture gamma rays, structural capture gamma rays and neutrons were calculated independently and summed.

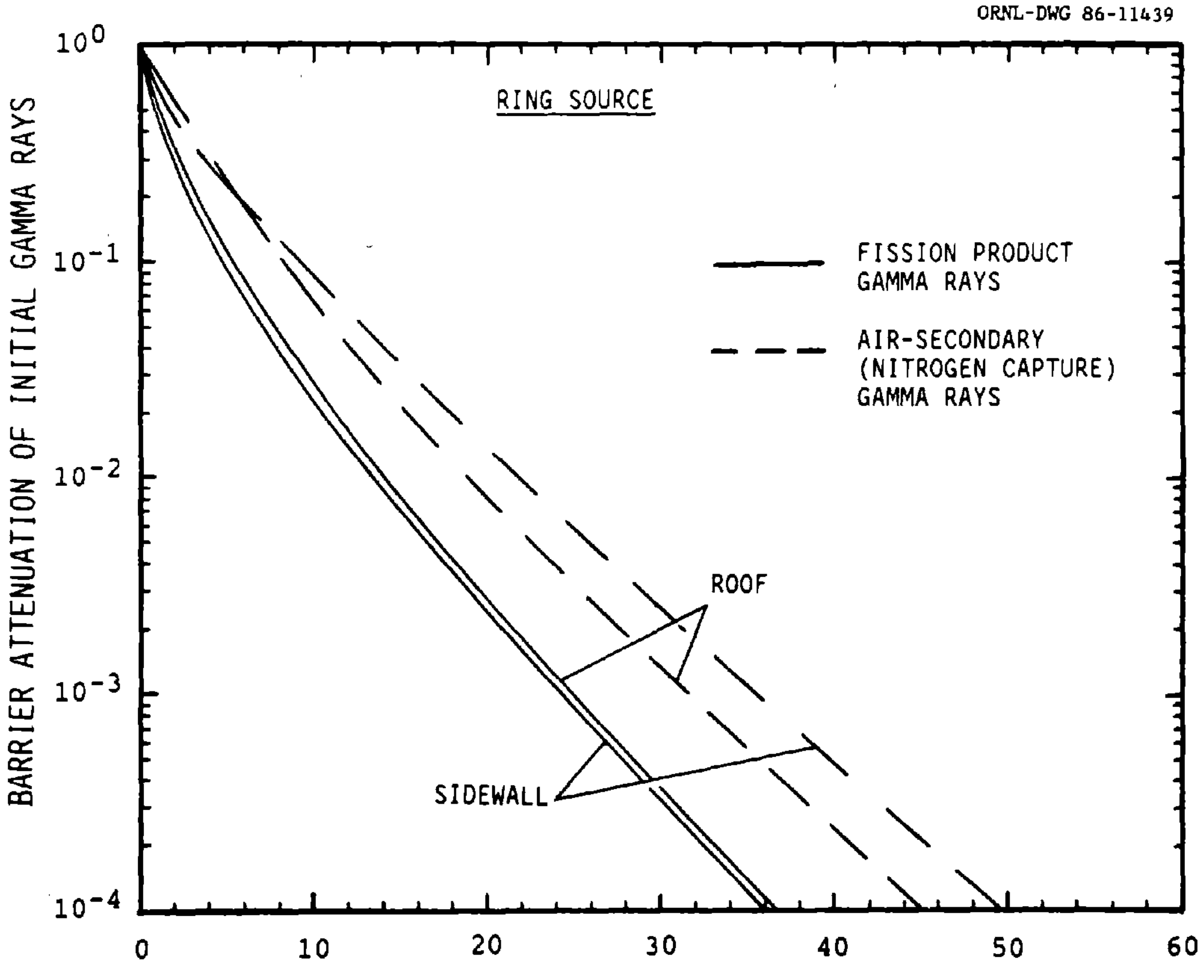


Fig. 4.2. Barrier attenuation of nitrogen capture gammas and fission product gamma rays (from an azmuthially averaged source simulating initial nuclear radiation).

Table 4.1. Initial radiation dose (R) in a fully buried basement with varying concrete thickness of the first floor

Weapon yield/ Overpressure	Initial radiation dose (R) inside shelter with a floor thickness of (inches)				
	12	14	16	18	24
1 MT, 20 psi	47	29	19	12	5
1 MT, 30 psi	166	104	70	46	17
100 kT, 20 psi	284	189	130	88	30
200 kT, 30 psi	974	658	457	310	104

SOURCE: Strope et al., 1985.

4.2.2 Geometry Shielding

The difficulty of calculating the radiation protection offered by a shelter space involves more than just the complexity of the radiation energy spectrum, the type of radiation, and its interaction with different types of matter. It also involves the nonuniformity of the shielding, because the arrangement of barrier shielding around the shelter volume is, in general, not of uniform thickness.

The technique of analysis involves dividing the shield into fairly uniform sections and calculating what fraction of the radiation gets through each element of the shield. The penetration of each element is by engineering estimation for mass thicknesses or by computer or hand calculations.

Convenient graphical techniques exist for doing these calculations. Figure 4.3 is a graphical method of estimating the solid angle subtended by a rectangular element. The solid angle is often expressed as the fraction of a hemisphere surrounding the detector. To determine the total exposure at some point inside the shelter, the solid angle subtended by each element of the shield is calculated and multiplied by the radiation coming through each element; then, the whole is added up to get the total amount of radiation entering the protected space.

The literature on radiation shielding is very large. The literature on shielding of people by shelters is only slightly less

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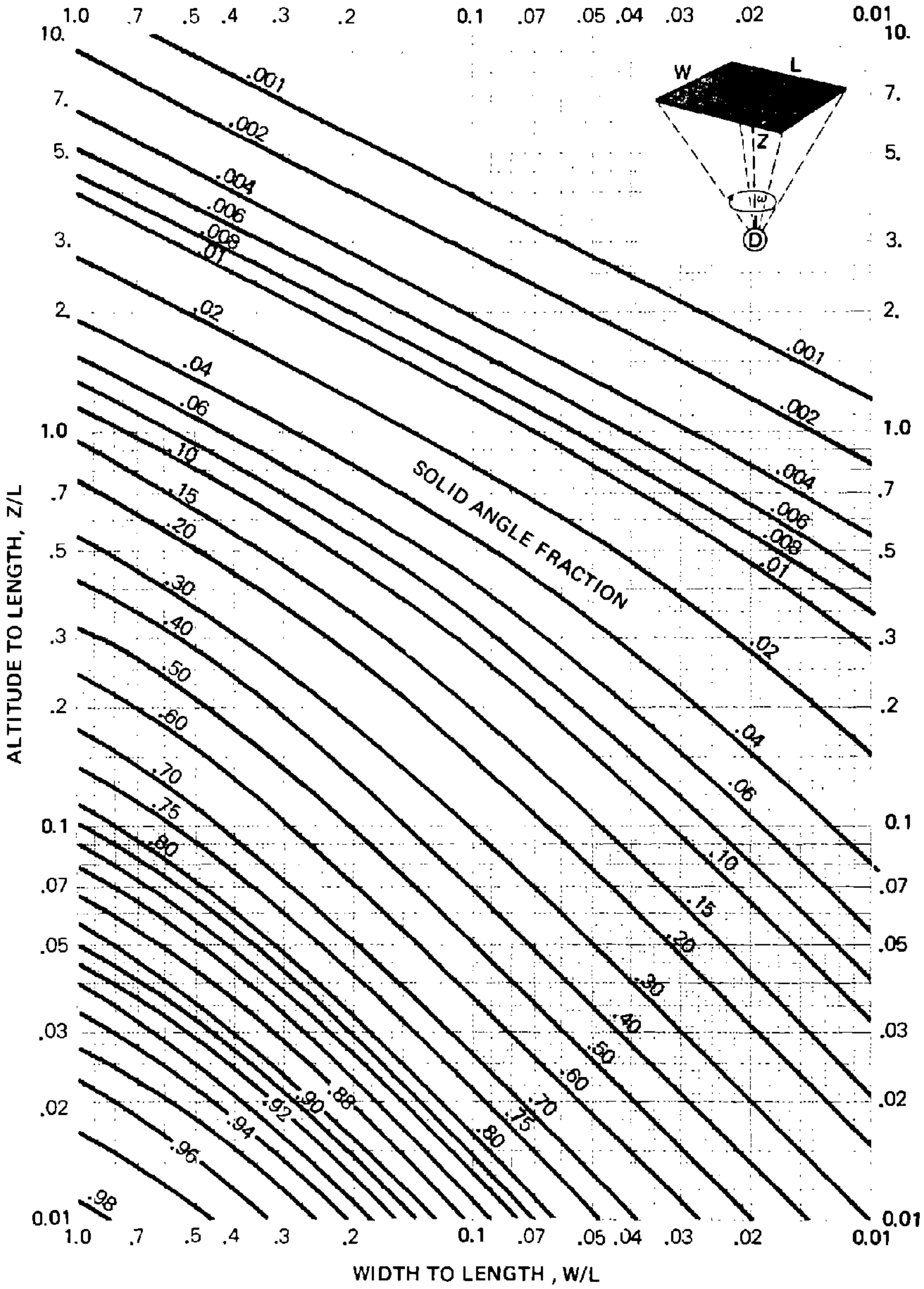


Fig. 4.3. Graphical estimation of solid angles.

large. Much of it was generated in the nuclear weapons tests in the 1950s, but a great deal was done with fallout simulation and calculation in the 1960s and 70s. The data that were developed in that time have been reduced to relatively simple graphical calculation techniques available in the various shelter handbooks and in shielding manuals. (Abbott, 1973; Beer and Cohen, 1975; Cain, 1964; Defense Civil Preparedness Agency, February1976, February 1978; Donovan and Chilton, 1961; Eisenhauer, 1964; Federal Emergency Management Agency, September 1980, 1981; LeDoux and Donovan, 1961; McDonnell and Velletri, 1966; Martin and Latham, 1963; Owen, 1962; Spencer, 1962; Spencer, Chilton, and Eisenhauer, 1980; Spring and McDonnell, 1967).

For very complex geometries where much more accuracy is desired, large computer calculations using fairly elaborate shielding codes can be employed. The Radiation Shielding Information Center at the Oak Ridge National Laboratory is the national repository of all shielding codes developed in this country and in most of the western world.

For additional information on structure shielding from both fallout and initial nuclear radiation, the following references are suggested: American Institute of Architects (1970); Beer and Cohen (1973); Brusse (1964); Burson (1963); Burson and Borella (1961); Cameron and Huff (1962); Clarke, Batter, and Kaplan (1959); Defense Civil Preparedness Agency (November 1972b, 1977, September 1978): Federal Emergency Management Agency (July 1982, September 1983); French, Price, and Tompkins (1965); Haaland (1983); Holmes and Narver, Inc. (1965b); Hubbell and Spencer (1964); Huddleston, Doty, and Ingold (1968); LeDoux (1959, 1960); McDonnell and Velletri (1967); Reynolds, Faw, and Robinson(1971); Robinson, Reynolds, Burre, and Faw (1969); Schmoke and Post (1974); Starbird, Velletri, MacNeil, and Batter (1963).

4.3 ENTRANCES, EXITS, AND CLOSURES

This section is concerned with entrances, exits, and closures for belowground civilian blast shelters designed for overpressures generally under 100 psi.

4.3.1 Entrances

Entrances must be constructed so that people can get into the shelter as efficiently (quickly) as possible and so that blast overpressure and radiation (especially initial nuclear radiation) will be kept out of the shelter--all this must be done at the least possible cost. The most effective techniques for accomplishing these objectives are fairly well understood.

The design of entrances is discussed thoroughly by Newmark (1963), Stevenson and Havers (1965), and Ferrito (1971b). Many types of entranceways are possible--ramps from the surface or from basements, stairs, corridors off basements, or vertical hatches with ladders. Most of the emphasis has been on stairs and ramps which have the highest capacity, permit people to carry things into the shelter, and are generally accessible to anyone who can walk. The vertical hatch entryway is much less expensive. It has the disadvantage that its throughput is much lower than stairs. A hatch entryway requires able-bodied people to negotiate the descending ladder; furthermore, it requires that the person use both hands, severely limiting the ability to carry objects.

Wiehle (1967) includes, in a cost study, detailed shielding analyses (for both fallout and initial nuclear radiation) of concrete blast shelters with concrete stairway entrances. An entryway capable of handling 200 persons per minute, according to this study, would have cost $10,000 in 1967 and approximately $20,000 in 1986.

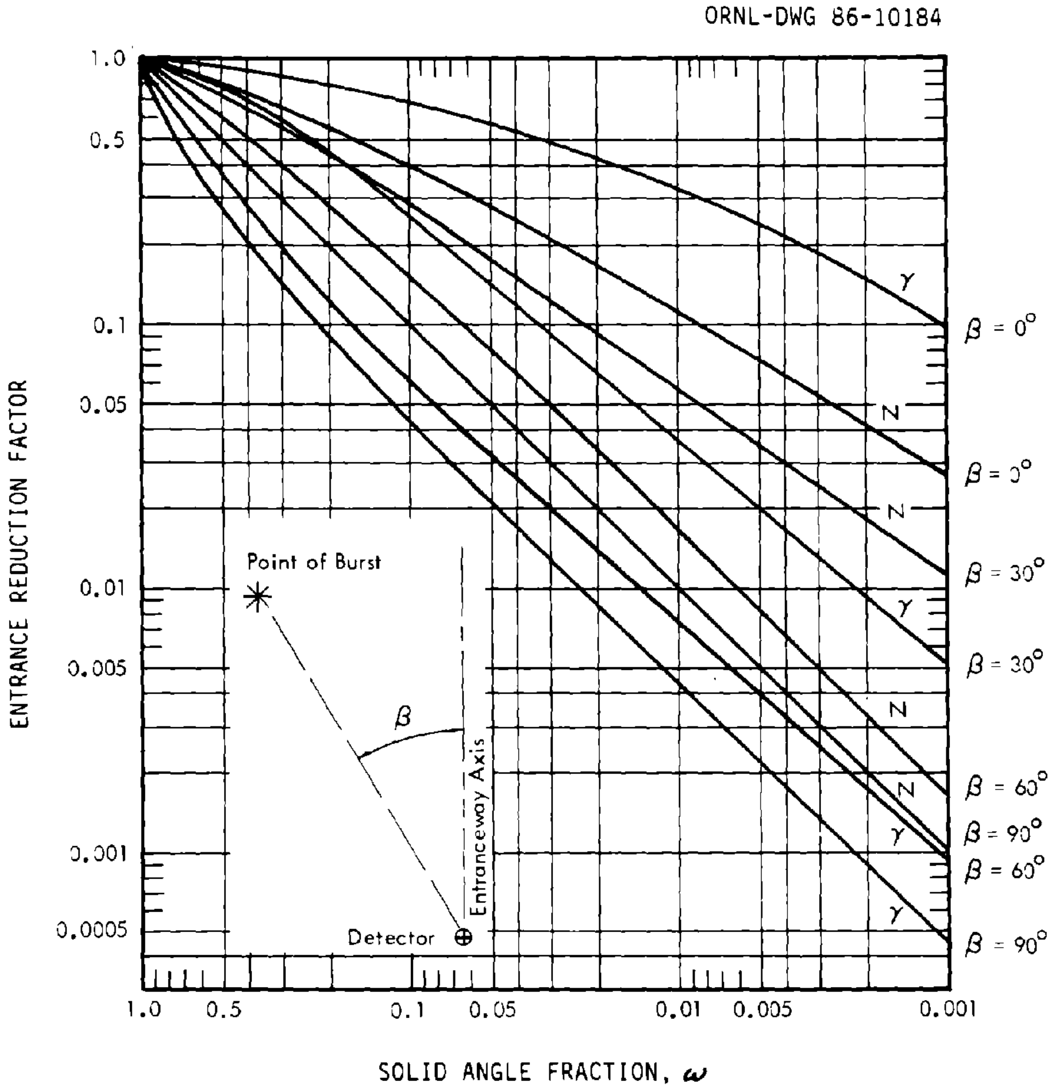
There seems to be some disagreement on the carrying capacity of stairs. Newmark uses 40 people per minute as an average loading rate per lane of stairs, with a peak of 60. Stephensen and Havers use 50 in agreement with Newmark. Wiehle has numbers ranging from 45 to 180 people per minute coming down what he refers to as a single stair.

For additional information on shelter entrances, the following references are suggested: Chilton (1958); Cohen and Weismann (1965); Cristy (1967b): Ferritto (September 1971a, October 1971): Haltiwanger, Tung, Feng, and Schnorbrich (1965); Pinkston (1964); Sinnamon, Austin, and Newmark (1955).

4.3.2 Radiation Protection for Entryways

The entryway of a shelter must attenuate radiation. For a blast shelter, the most difficult entryway design problem is often protection from initial nuclear radiation; fallout can also be troublesome in some areas. Very often protection factors of 100 or higher are required, depending on the threat to the shelter.

The penetration of radiation through entryways has been the subject of much experimentation. Some of the more careful and useful measurements on entryways were made by Cain, Clifford, and Holland (1964). A simplified procedure for analyzing shelter entrance passageways for fallout radiation attenuation is contained in publications by the Defense Civil Preparedness Agency (February 1978); Wiehle (1967); Stevenson and Havers (1965); and Newmark (1963). Figures 4.4 and 4.5 contain information for



(N = Initial Neutron Radiation; γ = Initial Gamma Radiation)

Fig. 4.4. Entrance reduction factor for initial nuclear radiation.

ORNL-DWG 86-10189

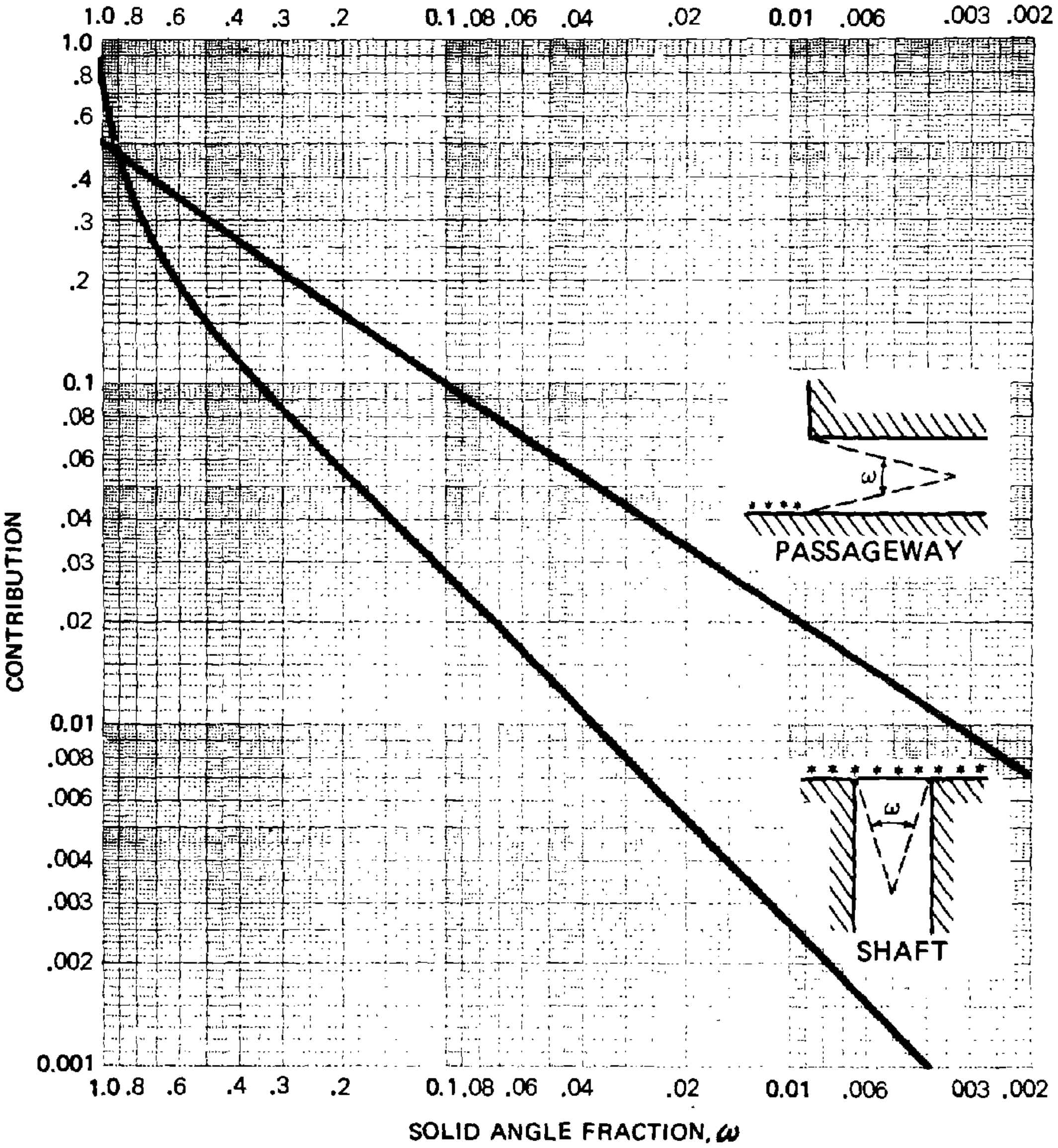


Fig. 4.5. Entrance reduction factor for fallout radiation.

graphically estimating the amount of radiation coming through an entryway.

Attenuation of radiation by the geometry of the entry passageways is usually the most economical approach, particularly if the entranceway must have enough length to go from the surface to an underground shelter.

Alternative approaches include the use of a massive blast door (1 ft or more thick), a shielding wall just inside the blast door or, for very small family shelters, moveable shielding stacked in the entryway. The latter can be concrete blocks stored inside the shelter or shelter supplies (particularly water). Entryways are better attenuators if they are long and narrow and have one or more right angle turns in them. A fallout protection factor of approximately 10 would be achieved by an entryway consisting of two right-angle legs each 7 ft long, 7 ft high, and 3 ft wide (following the method of Martin and Latham, 1963).

Additional information on providing protection for entryways and shelter openings may be found in: Auxier, Buchanan, Eisenhauer, and Menker (1958); Bigger, Crew, and Fuller (1965); Callahan, Rosenblum, and Coombe (1961); Chapman (1962); Chilton (1961); Condit (1962c); Fowler and Dorn (1962); Green (1962); LeDoux and Chilton (1961); Martin and Latham (1963); Terrell, Jerri, and Lyday (1962).

4.3.3 Doors

Doors can be horizontal, vertical, or inclined and can be hinged or rolling. They must be designed not only to resist the blast load, but also to transmit that load to a door frame which can ultimately resist the entire load. A structure made of fiberglass or corrugated metal is not strong enough to resist this concentrated load; the door will simply be blown into the structure. A strong flange or collar must be constructed around the door frame which must resist the total blast load on the door.

Doors are almost always designed to open outward if hinged. In this case, the door hinges and latches must be designed to take whatever rebound forces are developed by the door as well as the pressure load of the negative phase (approximately 3 psi). The rebound forces are usually assumed to be one-half the peak incident pressure.

In the early days of nuclear testing, many ingenious door concepts were proposed, (Cohen and Weismann, 1965; Forrestal, 1963). For rectangular entryways, reinforced concrete construction is very common, although built-up steel doors of various types have also been designed and constructed. Tests of a hinged rectangular membrane door, developed by the Federal Republic of

Germany, are reported by Cummins (1976). This door apparently does not fail at 100 psi. Newmark (1963) describes a variety of doors including a flush rolling door. Hyde and Kiger (1984) report a vertical door designed with steel reinforced concrete. This design is very light for a concrete door and rather economical, costing $1000 (in 1984) in small lots.

Doors can be constructed very economically for circular entryways. A 30-in.-diam by 3/8-in.-thick steel dome has been successfully tested as a hatch cover at 100 psi (Petras et al., 1979a, 1979b). Zimmerman and Chester (1984) of ORNL report the successful test of a very thin (2-mm) membrane-type door at 200 psi. This 34-in.-diam door, supported at its edge by a 2-in. pipe hoop which was filled with concrete (see Fig. 4.6), deflected 5 in. at its center yet maintained its structural integrity. In more recent ORNL tests, a simpler design consisting of a 1/8-in.-thick circular steel membrane, supported at its edge by a 1/2-in. x 2-in. steel bar rolled into a hoop, survived 50 psi while deflecting only 1-1/2 in. in a simulated 1-MT explosion.

FitzSimons (1958) reported on the successful tests of plywood and industrial doors at low overpressures in actual nuclear weapons tests.

For additional information on doors and closures for shelters, the following references are suggested: Barnett (1958); Carroll et al. (1985); Coulter (1982); Johnston (1959); Long (1959); Office of Civil Defense (January 1963a); Porteous (1962); Sandoval (1958).

4.3.4 Emergency Exits

Any shelter that has only one entryway should be equipped with at least one other emergency exit. The exit should be designed to bring people from the shelter into an area that is not likely to be covered by rubble. Swiss shelters specify emergency exits; their small, single-door shelters contain a vertical hatch-type escape exit (Cristy, 1973; Wiehle, 1967).

By far the cheapest emergency escape exit for an underground shelter is a 30-in.-diam piece of corrugated metal pipe which connects the shelter to the surface. This escape exit is filled with sand--if it is vertical or nearly vertical it should be entirely filled; if it is horizontal, only the last few feet near the surface need to be filled. This type of closure was demonstrated in an actual nuclear weapons test (FitzSimons, 1957).

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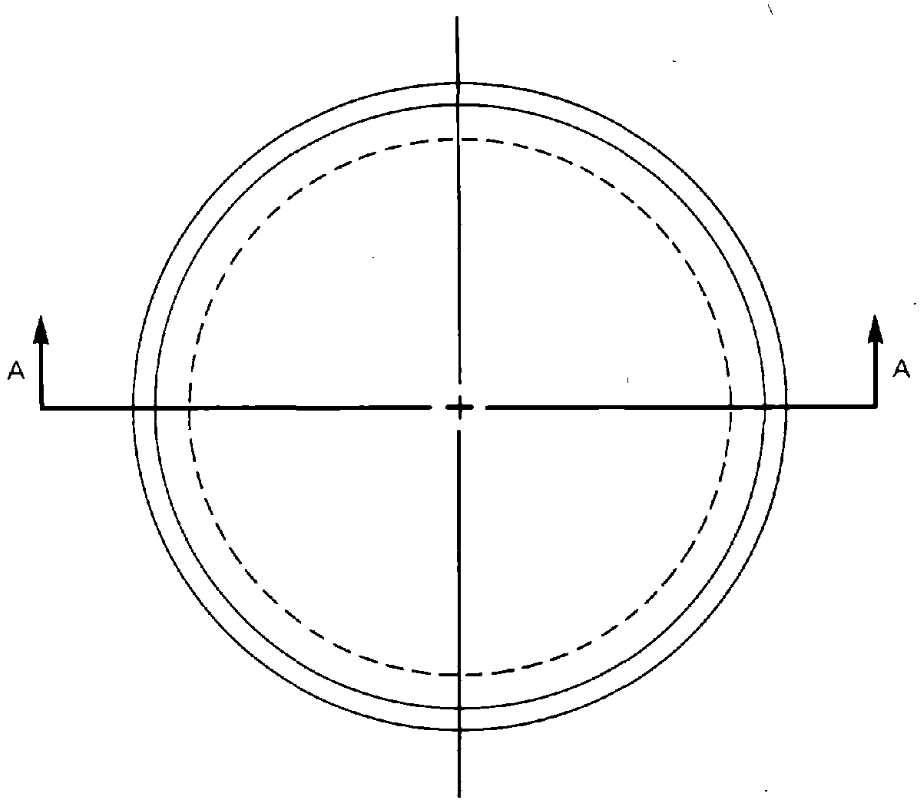
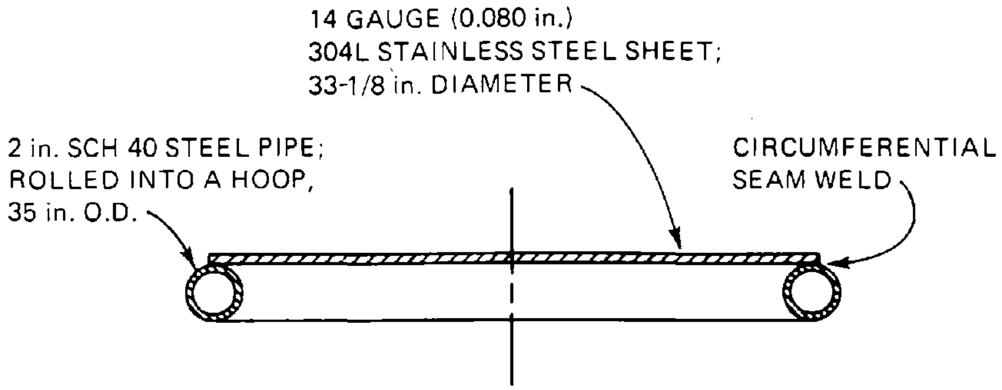


TOP VIEW



SECTION A-A

Fig. 4.6. Yielding membrane blast door (hatch) for use on vertical entryways.

4.3.5 Expedient Closures

An "expedient closure" is a semipermanent covering for a blast shelter opening (e.g., entryway or air intake). It is installed as part of an upgrading activity and is designed to keep the blast overpressure out of the shelter area.

Coulter (August 1979, 1983, 1984) has done an extensive series of shock-tube tests on designs of wooden closures for openings in walls. Various combinations of lumber and plywood were tested amd 5-in.-square oak beams across a 48-in. span were able to resist 50 psi. Various combinations of plywood were used to resist pressures from 20 to 80 psi on a 16-in. span.

Openings in walls can also be closed by piling sandbags against them in a sufficiently deep mound. Earth which is restrained by a relatively light door can be used to close an entryway, if there is adequate depth to develop earth arching.

During an actual high-explosive test, Wilton and Zaccor (1984) tested expedient closures which employed earth arching. They found that three layers of 12-ft corrugated metal sheet (22-gauge thickness; 0.0299 in.) could be used successfully as an expedient blast closure for a horizontal, grade-level entryway with a 4-ft span, if such sheets were covered with at least 18 in. of soil. Scale model tests indicate that this type of closure will withstand repeated blast loadings of 50 to 60 psi.

For additional information about expedient blast closures, the following references are suggested: Coulter (1982); Kearny (1979); Tansley (1985); Tansley and Bernard (1981); Tansley and Zaccor (1982); Wilton, Gabrielsen, and Tansley (1980, 1981).

4.3.6 Blast Valves

Blast valves are mechanical devices installed in the air intake and exhaust ducts of shelters. They are used to protect the occupants and equipment inside the shelter from the high pressure air of the external blast wave.

The shelter system components which need the most protection are dust and particulate filters, blowers, and sheet metal ducting inside the shelter. If the ventilation lines are small compared to the cross-sectional area of the shelter and are not pointed directly at the shelter occupants, then blast entering through the ventilation system presents little threat to the survival of the shelter occupants for external overpressures less than 50 psi. However, there are good reasons for installing blast valves on shelter air intakes. In addition to the possibility of damaging the ventilation system components, a high pressure jet of air entering the shelter can ricochet off the shelter walls and propel objects and debris around the shelter, possibly injuring the occupants. Large amounts of dust, which may be contaminated with radioactive fallout from previous nuclear explosions, can be blown into the shelter by an external blast. The noise, pressure, and violent air turbulence produced by jets coming through the ventilation ducts would produce a very unpleasant environment inside the shelter.

An excellent review of the various blast valve types has been presented by Cohen and Weissman (1965). Blast valves can be categorized as being either active or passive. Active valves are closed by some hydraulic, electrical, pneumatic, or mechanical system. Closure is initiated by a sensor which detects one of the prompt weapon effects: initial nuclear radiation, thermal pulse, or electromagnetic pulse. Active blast valves are designed so as to be completely closed (by means of the actuating system) by the time the blast wave arrives. Tests of valves of this type are described by Allen, et al. (1958), American Machine and Foundry Company (1958), Andon (1965), and Arthur D. Little, Inc. (1964). Most military shelters in the United States use blast valves of this type (See Fig. 4.7).

Passive blast valves are actuated by the impingement of the blast wave itself. Valves of this type have attracted the most design and development effort in the United States. Designers have attempted to achieve low flow resistance, minimum leakage of the high-pressure blast air, and low cost, simultaneously.

Several approaches have been tried in order to optimize the design trade-offs. A very low-cost approach is to place some resistance in the ventilation line. Examples of this are the German sand filter (Stephenson, 1963), shown in Fig. 4.8, and the Stephenson valve (Stephenson and Chapler, 1963); see Fig. 4.9. The German sand filter not only provides good blast protection (up to 100 psi), but it also filters the incoming air; filtration of radioactive dust particles, as well as certain chemical and biological agents, has been demonstrated (Asplin and Brooks, 1963). However, the German sand filter is a bulky unit. The additional airflow resistance provided by the bed of sand (1 in. of water pressure drop for 36-in.-deep beds at 4 cfm/ft^2) increases both the size and cost of the blower which is required to pull air through the ventilation system. The Stephenson valve is a section of the ventilation pipe filled with random chunks of rubber which are supported by a grate or plate. The pressure wave coming down the pipe will compress the rubber and increase the resistance to flow through the valve. Tests of the Stephenson valve have demonstrated its potential to resist blast overpressures up to 90 psi.

Attempts to reduce the amount of high-pressure leakage from passive blast valves have included designs with delay lines. One

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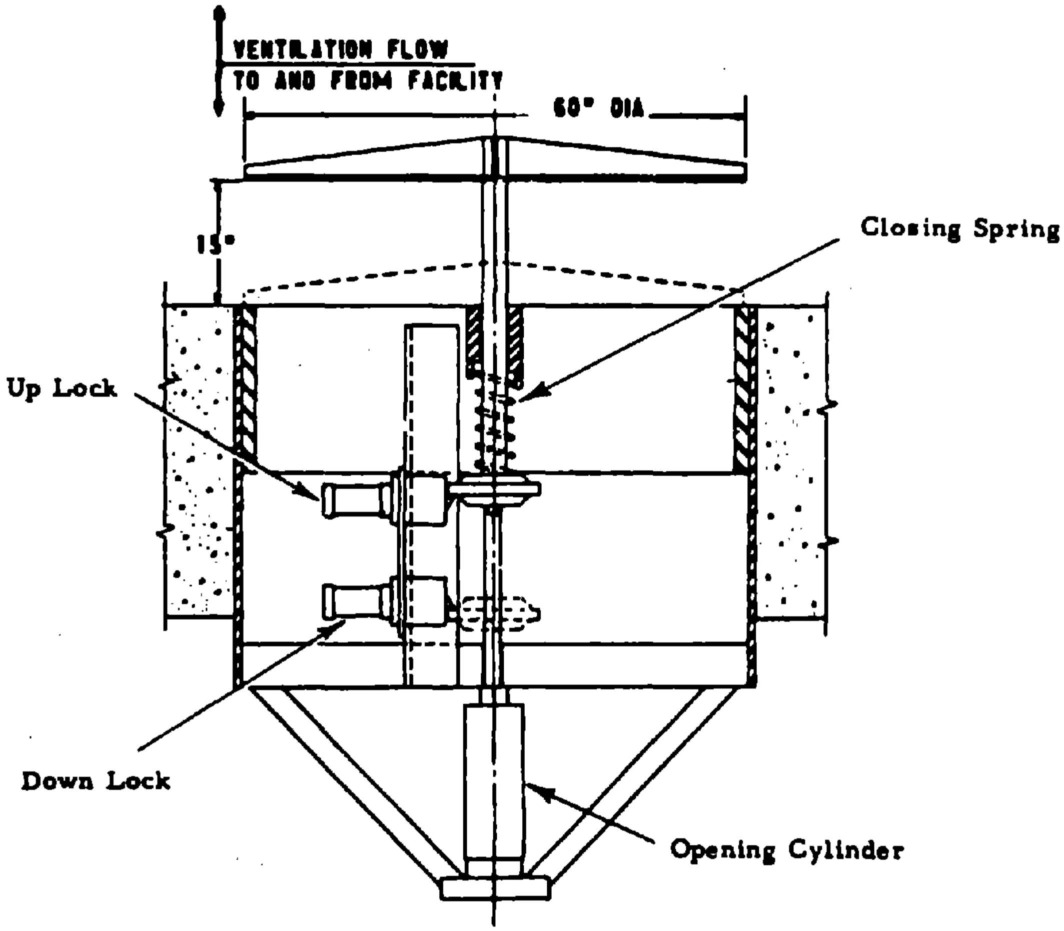

Fig. 4.7. Remotely actuated blast valve.

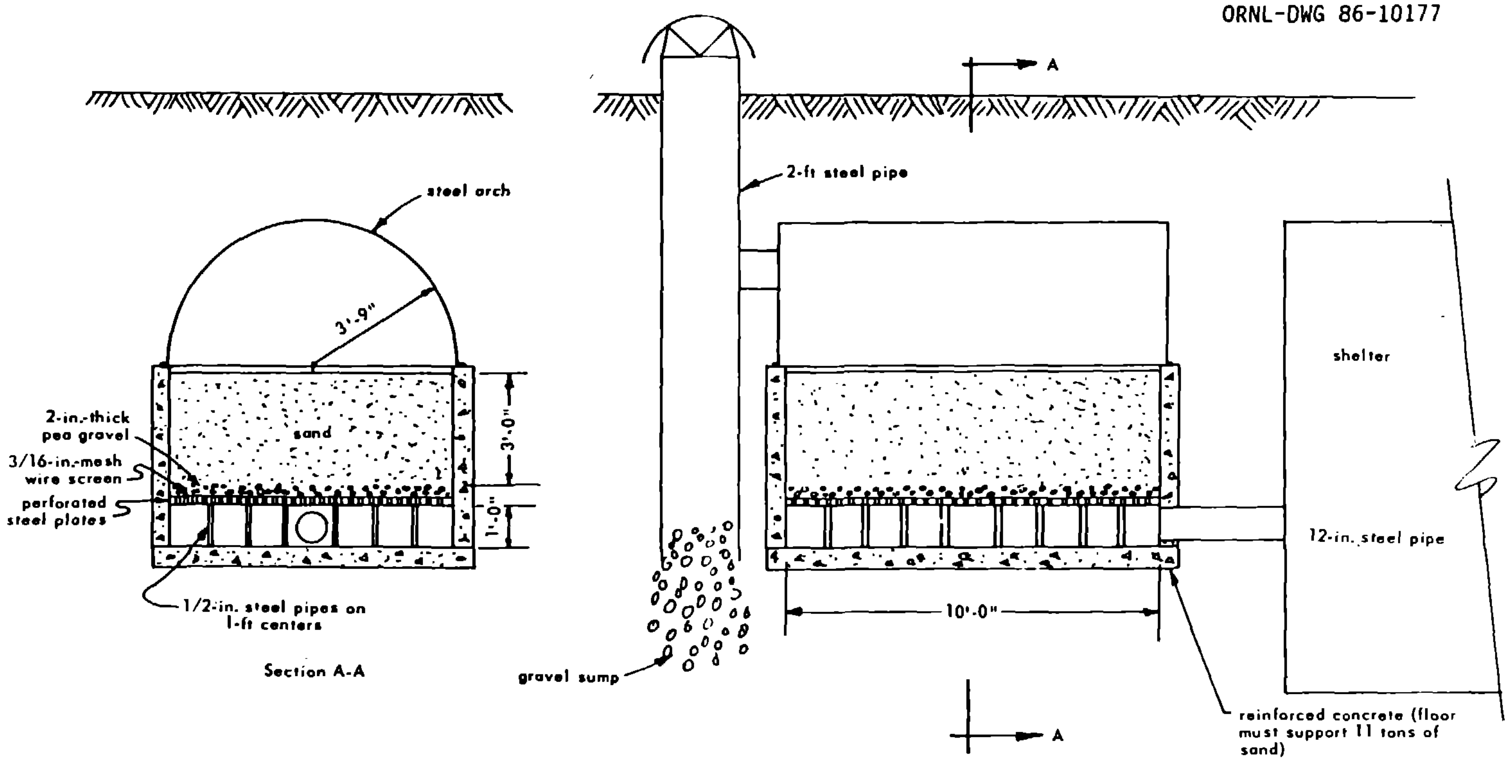

Fig. 4.8. German sand filter.

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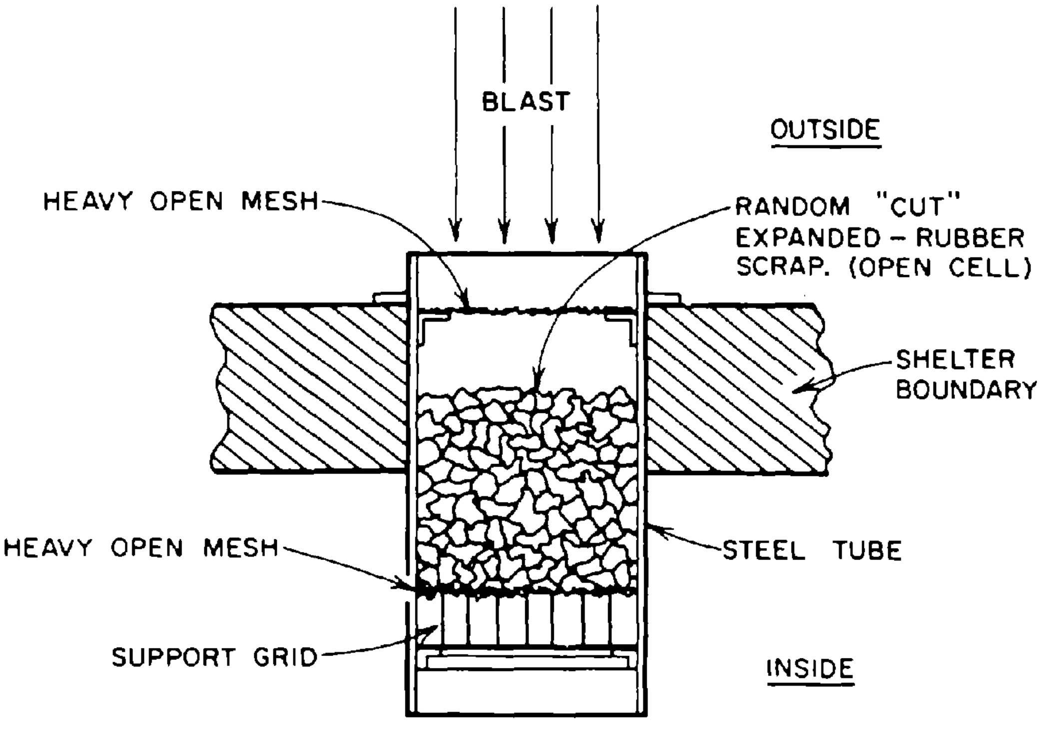

Fig. 4.9. Stephenson blast valve.

example is the Breckenridge valve (Breckenridge, 1962); see Fig. 4.10. The Breckenridge valve is fairly economical, but it requires additional lengths of ventilation ducting and occupies considerable volume.

The plate valve (Fig. 4.11) and its close relative, the swing valve (Fig. 4.12), are straightforward approaches to closing off a round ventilation pipe with a circular disc of steel or aluminum. In the piston plate valve, the disc is supported on a central sliding rod and is pushed against the end of a section of intake pipe by the blast wave. The piston plate valve was invented by workers at the U.S. Naval Civil Engineering Laboratory (Norbutas, 1972). In the swing valve the disc is hinged at one edge and is slammed shut like a trap door over the intake pipe. The plate valve was one of the earliest designs that was extensively tested in the 1950s nuclear weapons tests (Roembke, 1958a). A swing valve was tested and analyzed by Kiang (1967).

The Swedish blast valve (Chapler, 1965; Hellberg, 1962), see Fig. 4.13, is a modification of the flat plate valve. In the Swedish valve, the disc is cone-shaped; it can move into a closed position during both the positive and negative phases of the blast. Springs reposition the disc into the open position following the blast.

In an attempt to simplify mechanical complexity, at least two types of spring valves were developed. These consist of a strip of spring steel which is pressed against a slotted plate by the blast, thus closing off the airflow. In the Chevron valve (Fig. 4.14) the support plate is flat, and the spring steel is arched or curved (Kiang, 1967). In the LUWA valve (Fig. 4.15) the spring is flat, and the support plate is curved (Chester, 1969). Spring valves are reliable and close very fast (in milliseconds) but are fairly expensive.

Another approach to mechanical simplicity and reduced closing time is the flap valve. This consists of a springy or hinged sheet of material anchored at one edge; this sheet is pushed by the blast over a support grid, thereby blocking the passage of the blast wave. In the Buships valve (Norbutas, Chapler, and Pal, 1971) a springy titanium flap is pushed over rectangular openings in a supporting metal grid. In the Kearny valve (Fig. 4.16), flaps of automobile tire rubber are pushed over slots in a wooden support grid (Kearny and Chester, 1974; Kearny 1979).

The louver valve (Nevrincean and Witt, 1972; Ort and Mears, 1959) is a series of hinged flaps which are pushed shut by the blast and must be manually re-opened (Fig. 4.17). The buckling plate valve developed by the U. S. Naval Civil Engineering Laboratory is similar in concept to a louver valve with the addition of spring assistance to shorten the closing time (Wil-

ORNL-DWG 86-10179

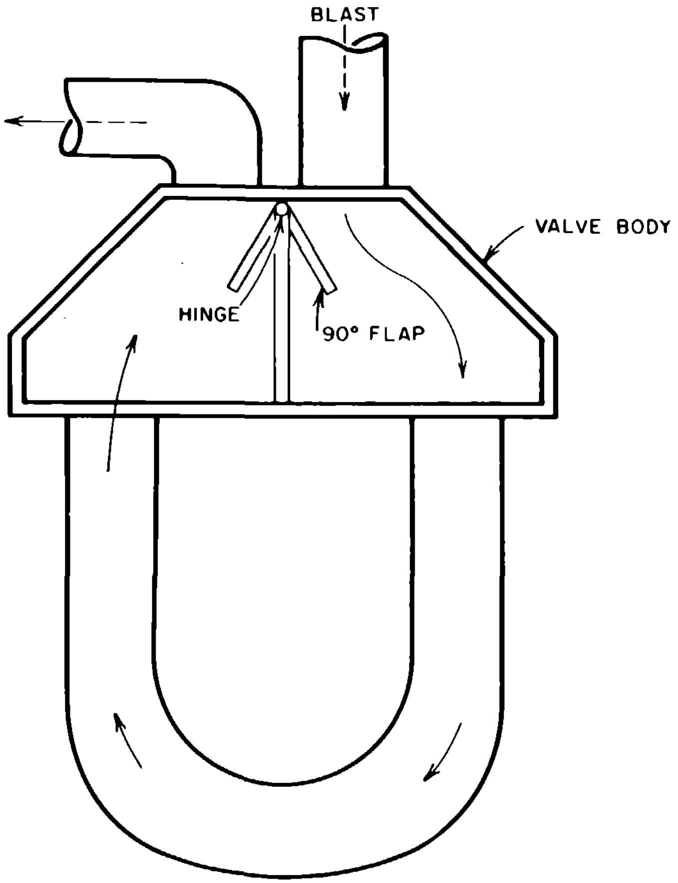

Fig. 4.10. Breckenridge blast valve.

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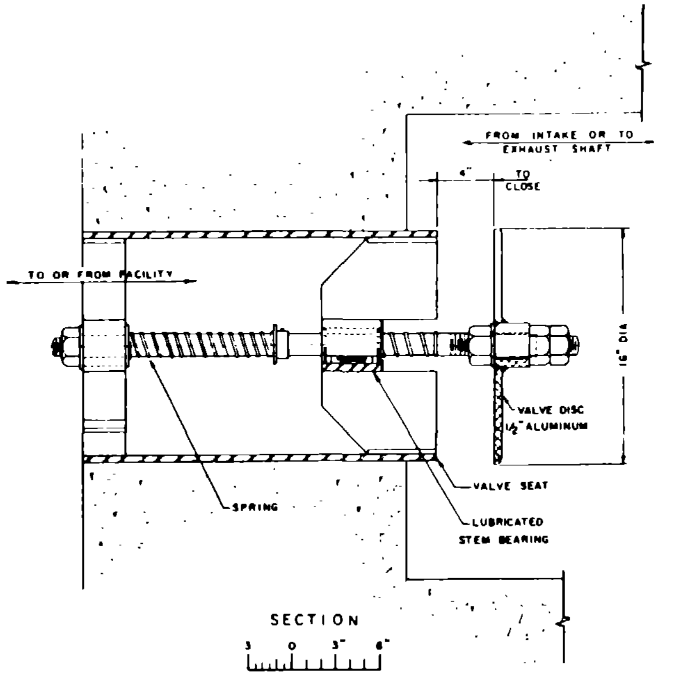

Fig. 4.11. Plate valve.

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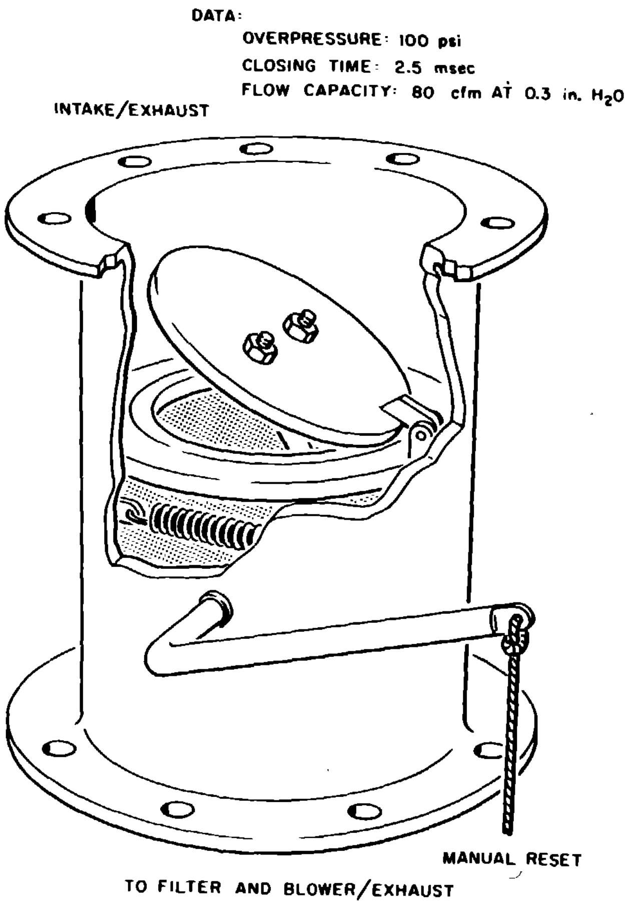

Fig. 4.12. Swing valve.

ORNL-DWG 86-10195

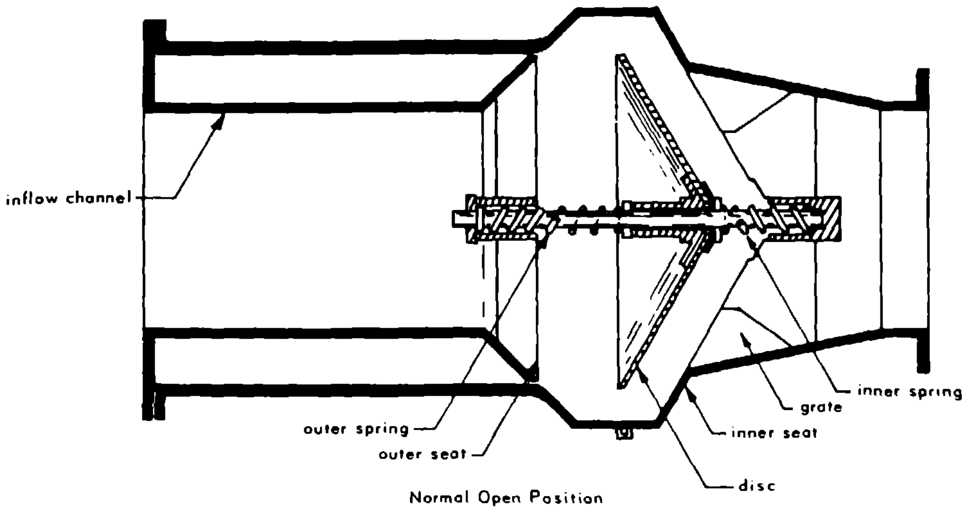

Fig. 4.13. Swedish blast valve.

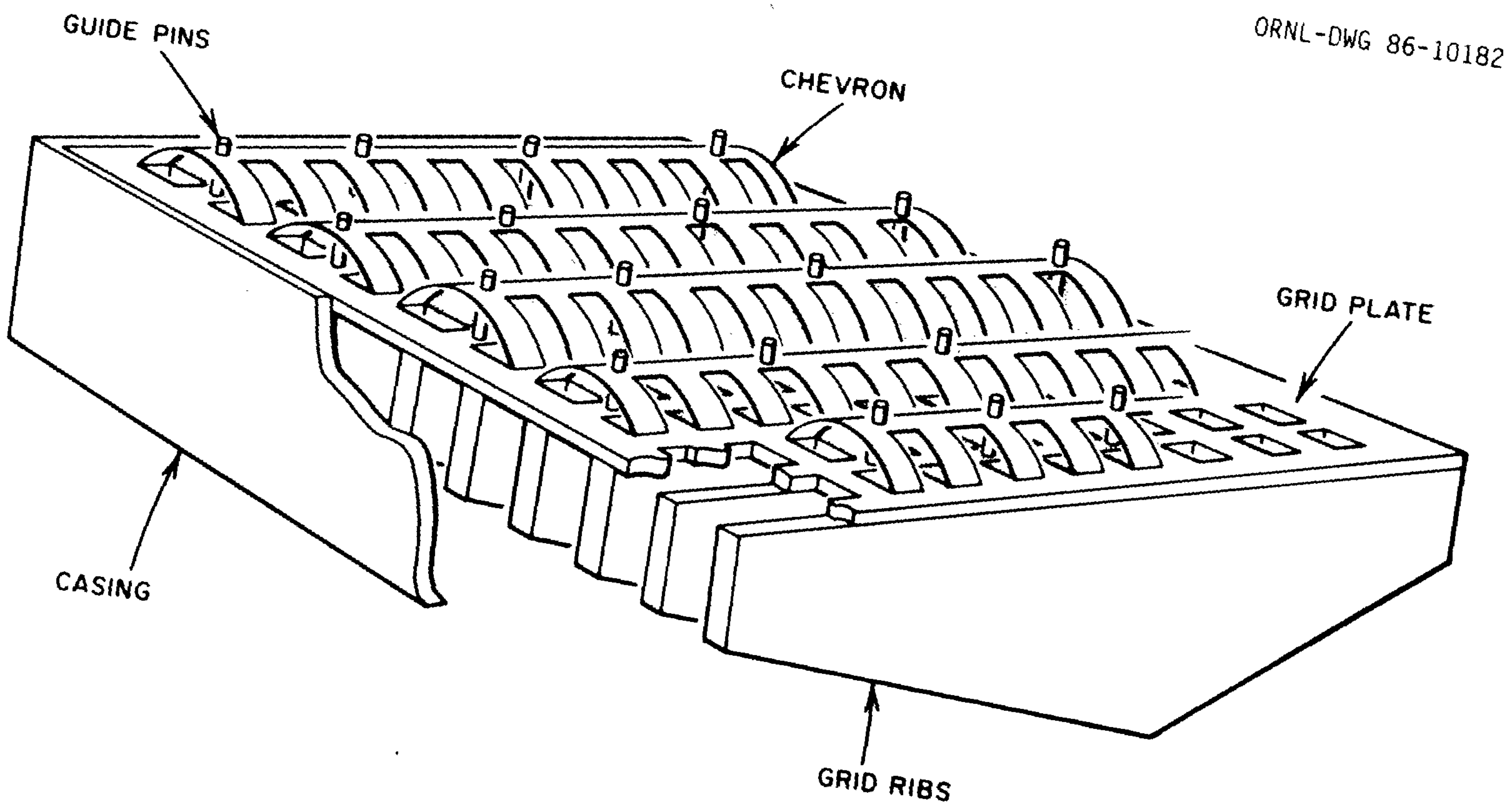

Fig. 4.14. Chevron valve.

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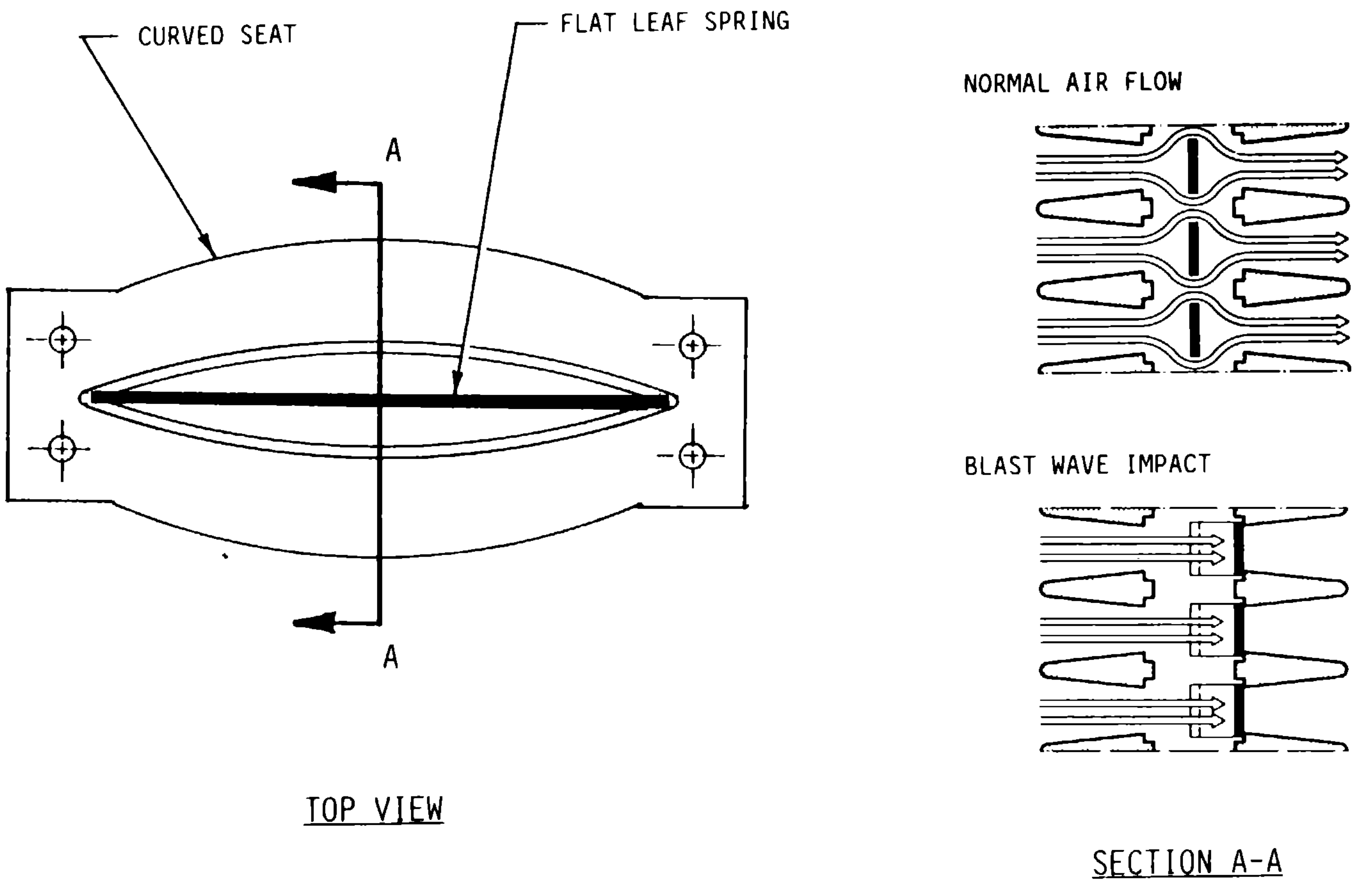

Fig. 4.15. LUWA (Swiss) blast valve.

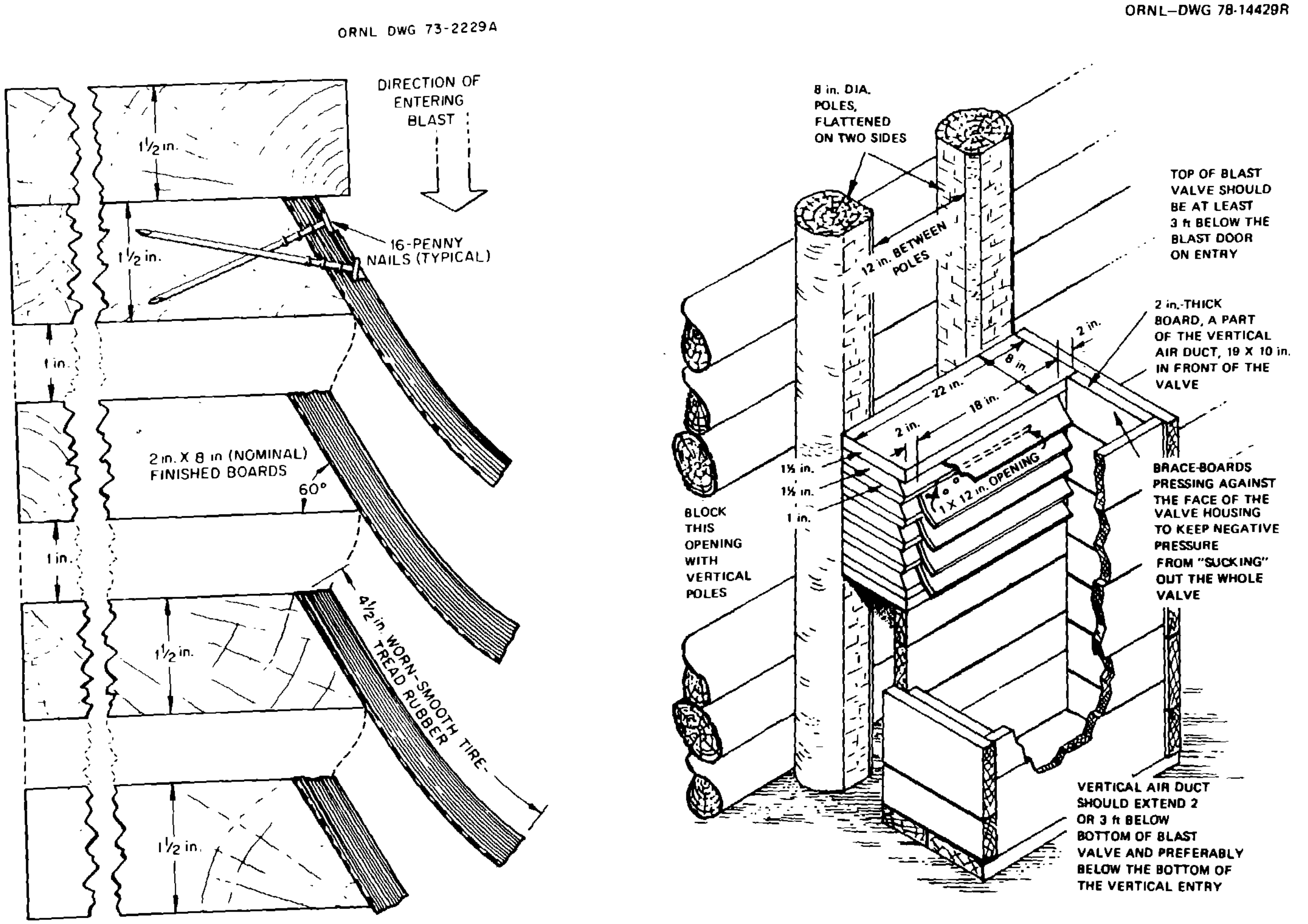

Fig. 4.16. Kearny blast valve.

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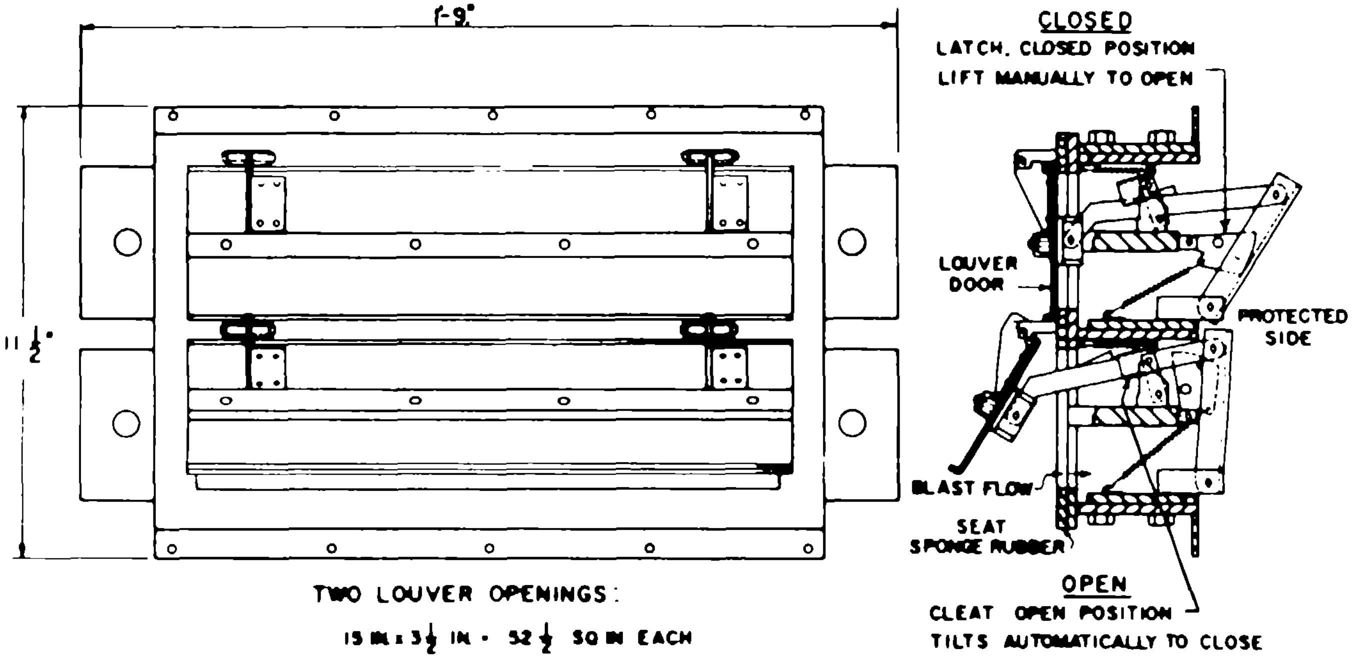

Fig. 4.17. Louver valve.

liams and Pal, 1971). It is mechanically complex and probably too expensive for civilian application.

As far as we have been able to determine, there are no passive blast valves being manufactured in the United States at the present time (1986). Table 4.2 lists several foreign companies which manufacture blast valves and other shelter equipment. Only TEMET Oy of Finland has a sales representative located in the United States.

Table 4.2. Shelter equipment vendors (international).

Company	Address
Andair AG	CH-8450 Andelfingen Switzerland
The Batley Valve Co., Ltd.	Longlands Industrial Estate Wakefield Rd., Ossett, West Yorkshire, WF5 9JF Great Britain
JP SHELTEC AB	Box 1163, S-141 24 Huddinge Sweden
LUWA	Kanalstrasse 5 CH-8152 Glattbrugg-Zurich Switzerland
Rickenbach & Company AG	Lindenstrasse 77 CH-9006 St. Gallen Switzerland
TEMET Oy	Asentajakatu 3 SF-00810 Helsinki, Finland
TEMET USA, Inc.	ATTN: Mr. Kenneth Burbach P. O. Box 439 Great Falls, VA 22066 Phone: (703) 759-6000

Probably the best course of action for an American desiring a blast valve for a private shelter would be to improvise a flap valve. A flap valve followed by a plenum chamber (expansion chamber) will protect a blower in the overpressure ranges of interest. Air filters should not be installed in the system until they are needed; spare filter elements should always be kept on hand.

For additional information on blast valves, the following references are suggested: Forrestal (1963); Hellberg (1963); Hughes-Caley and Kiang (1966); Ingram (1963); Kessler and Levoy (1962); Office of Civil Defense (1963c); Stevenson and Havers (1965); Williams and Pal (1971).

4.4 VENTILATION

4.4.1 Ventilating Equipment

The typical ventilation system of a nuclear shelter consists of an intake/exhaust structure, intake/exhaust ducts, blast valves, filters, blowers, heating/cooling equipment, and an air distribution system. Of these components, only the intake/exhaust system and the blast valves are unique to the nuclear weapons environment. The rest of the equipment can use standard, commercial heating, ventilating, and air conditioning (HVAC) technology.

In fallout shelters, as opposed to blast shelters, blast--resistant intakes and blast valves are not required. Shelter spaces identified in the National Fallout Shelter Survey (Tolman, Lyday, and Hill, 1973) may not require a powered blower system, especially if the shelter space is aboveground in a tall building. Many more of the shelter spaces, particularly those belowground, require some type of forced or induced ventilation, primarily if they are going to be occupied at the density of 10 ft^2 per person. As estimated by Tolman, Lyday, and Hill (1973), 21 million spaces could be added to the 173 million spaces in the 1973 inventory if adequate additional ventilation were arranged. Because of the critical importance of ventilation, a great deal of effort has gone into the technique of ventilating National Fallout Shelter Survey space.

Most of the effort and study that has gone into ventilating fallout shelter spaces has been directed at ventilation methods that do not require electric current for operating the blower. There are two principal types of manually-operated air movers for ventilation of fallout shelters. The more conventional is a pedal-driven rotary fan; see Fig. 4.18. Much development effort has been put into ventilation kits making use of this fan: Buday

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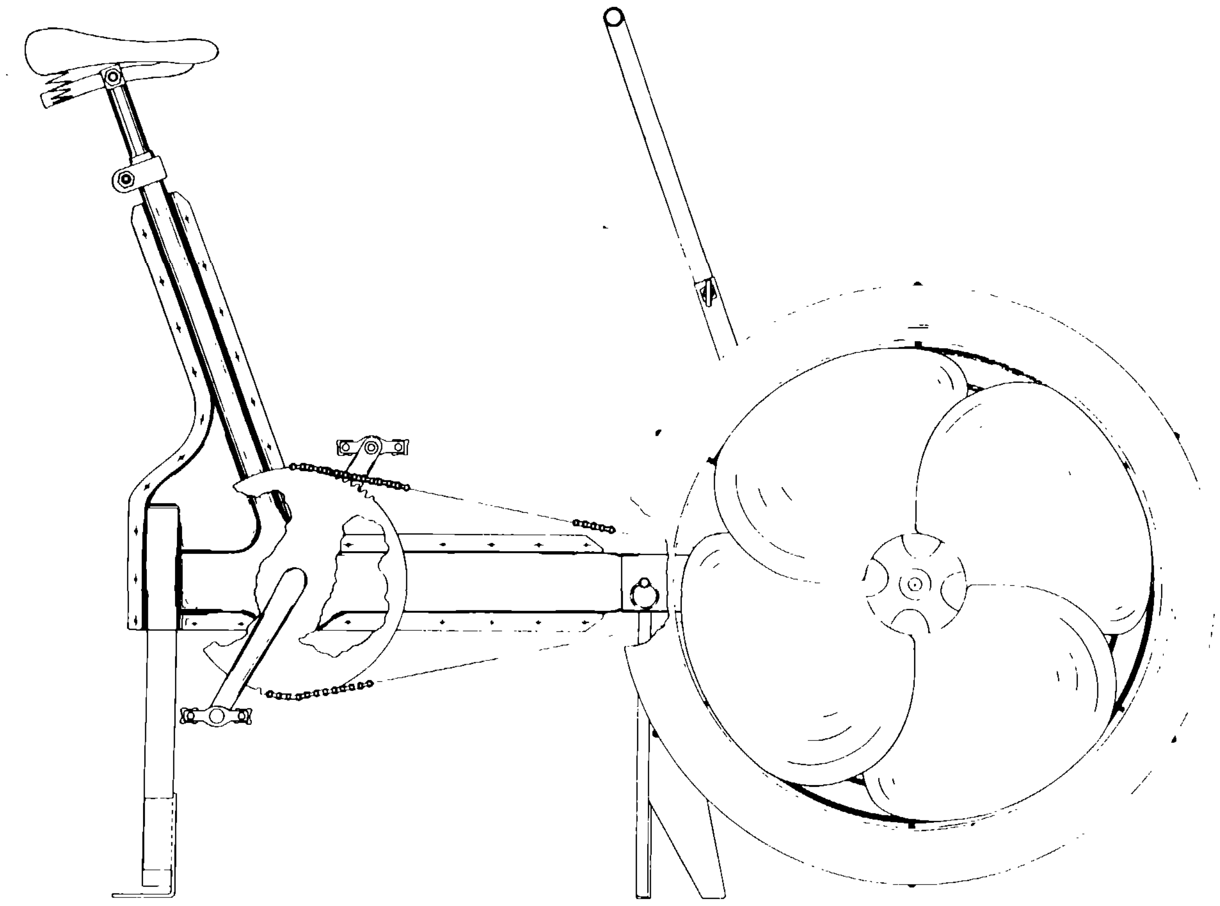


Fig. 4.18. Schematic drawing of pedal ventilator.

(1980); Kapil, Sitko and Buday (1969); Libovicz, (1969); Libovicz and Behls, (1965); Libovicz, Neveril, and Behls (1965); MacDonald (1965); and Vermes and Wachtell, (1965). The fan is very often used with a flexible plastic duct. A modular version of the machine has been designed to be driven by up to 4 people pedaling. The fan will produce flow rates of a few thousand cubic feet per minute at a pressure of a few tenths of an inch of water.

The other air-moving device is called a Kearny air pump (KAP) (Kearny, 1972, 1979; Hori, 1967); see Fig. 4.19. This device, also known as a punkah pump or a pendulum pump, consists of a mesh-covered frame with attached plastic flaps that open when the pump is on its return swing. The frame is often designed to fit into a doorway and is hinged at the top. It is operated by pulling a string attached about one-third of the way from the top of the frame. One man can move 5000 cubic feet per minute of air through a doorway into an open room. The Kearny pump delivers less air at lower pressure than the package ventilation kit fan; however, it uses far less energy. Its natural limitation of a few thousand cubic feet per minute makes it unsuitable for ventilating large spaces or for supplying air through high-pressure-drop ducts or filters. It is very useful for redistributing air in blind rooms off a main corridor if the rooms are not too large.

Comparisons of the Kearny pump and the package ventilation kit have been made by Kapil, Sitko, and Buday (1969); Buday and Klima (1979); York, Reeves and Wallace (1982); Kapil and Rathmann (1971); and Rathmann (August 1970). In 1979, Buday and Klima estimated the cost of the package ventilation kit at about 2-1/2 times that of the Kearny air pump.

Much less effort has gone into the development of hand-driven blowers; although, Vermes and Wachtell (1965) have reported on the design of a 65% efficient hand-cranked blower.

For additional information on shelter ventilation and ventilation equipment, the following references are suggested: Beck, E.J. (1963); Bigger, Crew, and Fuller (1965); Brusse (1964); Defense Civil Preparedness Agency (May 1978); Dennis, Billings, and Silverman (1962); Ducar, Baschiere, and Engholm (1963); Franke and Schultz (1983); Haerter (1984); Henninger, Krishnakumar, and Tsal (1980); Hill, Caldwell, and Grogan (1965); Isenberg et al. (1966, 1968); Krishnakumar et al. (1983, 1984); Libovicz and Behls (October 1965); Lis and Behls (1968); Murakoa (May 1961); National Academy of Sciences (1960); Neveril and Behls (1965); Office of Civil Defense (January 1963b); Rathmann (1969); Scott and Holmes (1965); Svaeri and Dembo (1965); Svaeri and Stein (1967); Taylor and Gonzales (1965); Whitehill, Mullikin, and Kubal (1965); Wright, M.D., et al. (1975); Wright, Berryhill, and Wallace (1981); Wright, Hill, and Botkin (1973); Wright, Hill, and Sawyer (1970); Wright, Hill, and Whitaker (1971); York and Armstrong (1980).

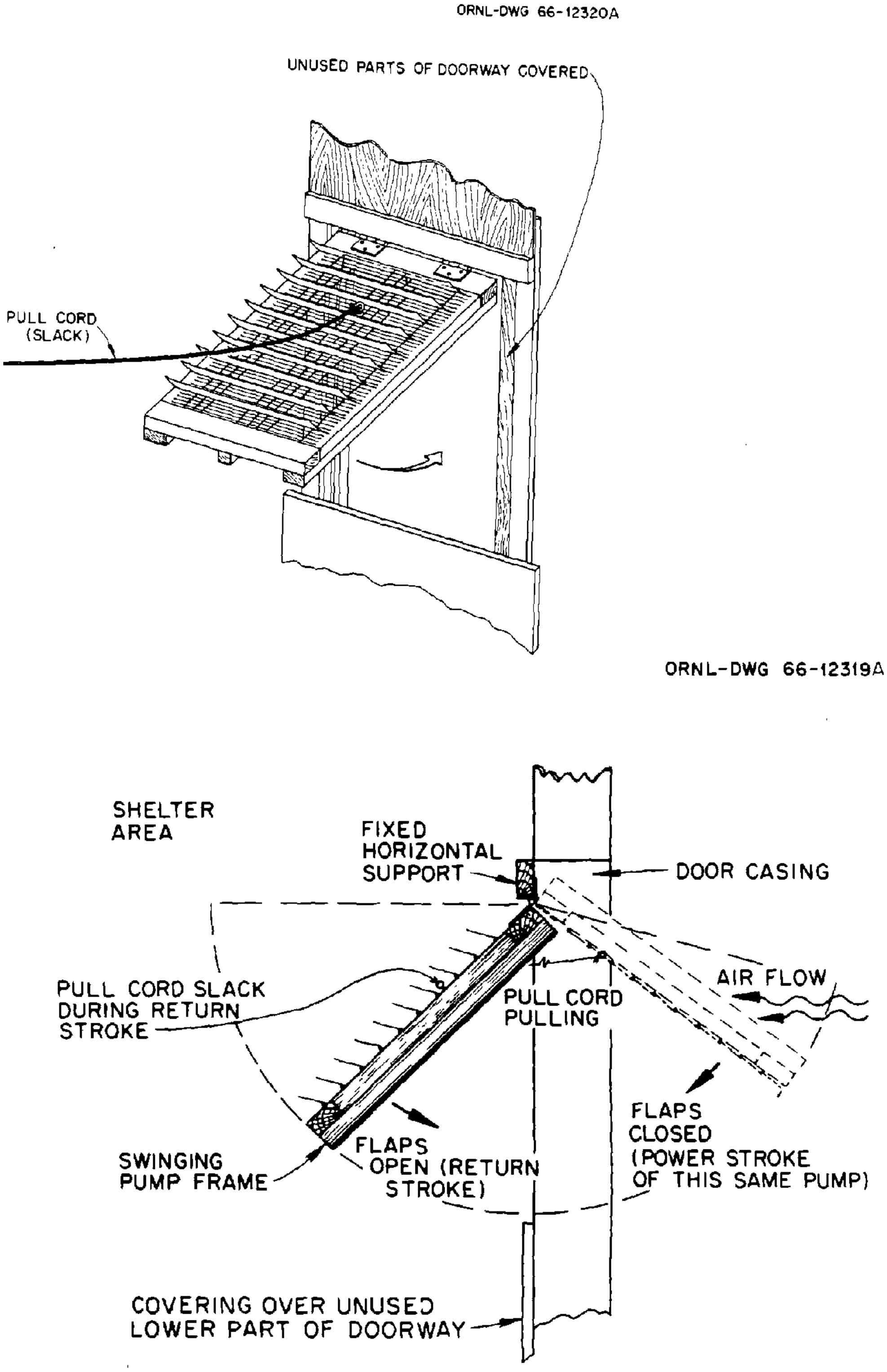


Fig. 4.19. Kearny air pump.

4.4.2 Cooling

Much of the ventilation requirement for shelters during much of the year is for cooling the occupants. The subject of providing cooling systems that could remove both heat and moisture from shelter air has received a modest amount of investigation. Ambrose and Commerford (1965) looked at the feasibility of an ammonia absorption cooling system for shelters. Hummell (1965) proposed and examined an air-cycle cooling system which would compress incoming air, cool it, and then let it expand into the shelter. Hummell and Beck (1966) examined the unusually imaginative prospect of using methanol as a heat sink and then using it as fuel in a motor/generator. Breck (1967) and Everetts, Witt, and McLaughlin (1970) analyzed a conventional vapor-compression air conditioner for shelter application. All of these methods involved high capital costs and are not at all competitive with providing larger ventilation air flows by manually powered air pumps.

An approach that is more nearly competitive with cooling-air ventilation is the use of cooling water from wells, if it is available. Well water in most parts of the country has a temperature under 60°F. Circulated through a fan/coil system, it could provide cooling at relatively low cost. Such a system has been examined by Hughes-Cayley (1966) and Guy B. Panero (1974).

For additional information on ventilation for shelter cooling, the following references are suggested: Allen (1970, 1972); Baldwin (1967); Barber, Kusuda, Reynolds, and Powell (1972); Baschiere, Rathmann, and Lokmanhekim (1968); Flanigan and Gonzales (1964); Humphreys, Henschel, and Lee (1966); Kearny (November 1966); Sampsell (1965); Stephenson (1966); Strohecker (1966, 1967); Wright, Botkin, and Hill (1974).

4.4.3 Closed Systems

Very early thinking about civilian shelters gave some consideration to systems that could be closed completely (buttoned-up) if the ventilation intakes were covered with large amounts of burning debris. Military shelters, such as NORAD Headquarters in Cheyenne Mountain, have this capability (Charanian, Glueckert, Barile, and Zeff, 1963).

Charanian and Zeff (1964) did some experimental evaluations of systems that would permit shelters to be buttoned-up for 24 hours. They used a CO_2 absorber and high-pressure oxygen bottles. Present thinking is not to build isolated shelters in areas that can be covered by burning rubble, but to move people out of such areas before an attack or else use some type of tunnel shelter that will enable people to walk out of the area. Additional information on closed shelter systems is contained in Defense

Civil Preparedness Agency (May 1978) and in Williams (1968, 1970).

4.4.4 Chemical and Biological Protection

A limited amount of experimentation was done in the 1960s on protection of civilian shelters against chemical and biological agents. Westinghouse Electric Corporation (1962) developed specifications for a chemical, biological, and radiation (CBR) filter and fabricated a prototype. Petty and Brooks (1964) estimated the cost of providing biological agent protection in fallout shelter both above- and belowground. The cost involved using high-efficiency particulate air filters and sealing the shelter volume so that it could be pressurized with filtered air. The costs were generally in the neighborhood of $5 to $10 per space in 1964 and would be very nearly double that in 1986. A decontamination facility that would permit people to move in and out of a shelter with a contaminated exterior added approximately another factor of two to the cost of the protection.

The advent of the cruise missile and apparent Soviet activity in chemical and biological weapons suggest that biological agents should be considered in strategic defensive systems, especially shelters (Chester and Zimmerman, 1984). Additional information on chemical and biological protection is contained in Shelter Environmental Support Systems, (Defense Civil Preparedness Agency, May 1978).

4.5 FOOD

Even though most Americans eat three meals each day, the fact is most people could survive in a shelter without food during the first two or three weeks following an attack. Exceptions would be infants, small children, the aged and the sick, all of whom have special nourishment needs. Food is far down the list of essential shelter items; air and water are much more important.

Several studies have evaluated government rations for use in group shelters (Cecil, 1968; Chow, 1979; Newling and Hayes, 1966a, 1966b; Shepherd et al., 1963, 1964, 1965, 1966, 1967; Stone, Oliver, Koehn, and Singleton, 1966; Stone, Oliver, and Singleton, 1967; Tate, Mathews, and Stone, 1969); however, no such packaged ration is currently available for U.S. shelter use. Information on the selection and storage of individual foods for family shelters has been adequately presented by Batchelor (1974), Dickey (1969), Kearny (1979), and Oster (1984b).

Large, well-dispersed food reserves would have to be an essential part of governmental planning for population survival after a nuclear attack.The largest U.S. food reserves are contained in unprocessed grain storage -- mostly on individual farms. Interregional transport of foods and regional self-sufficiency have been evaluated by Cabraal, Dhaliwal, and Faby (1984).

Additional information on food and food storage is contained in the following references: Cannell (1962); Federal Emergency Management Agency (1973b); Franz and Kearny (1979); Levy (1963a, 1963b); Long (1982); Oster (1984b, 1985a).

4.6 WATER SUPPLY

A water supply is an absolutely indispensible component of any shelter. In one or two days without it, thirst will drive people out of the shelter to seek water. Without water, people will begin to die in about four days.

The minimum emergency water supply is approximately one quart per person per day, but this may be disastrously inadequate in hot weather. One gallon per day is desirable and is also adequate, if there is not excessive heat stress. This implies a requirement for storing approximately 14 gallons for each shelter occupant for a two-week shelter stay. This water can be stored inside the shelter in single tanks, in multiple, small containers, or in large buried tanks external to the shelter.

Notable among the research which has been done, Kapil (1970) experimented with the development of a cubical water container; Neveril and Kapil (1967) studied the development of a container liner; and Gorecki and Jago (1971) developed a 400-gallon collapsible container with a pump. Kearny (1979) describes several expedient methods of storing water including the use of plastic trash bags inside various containers, including pillow cases and holes in the ground dug next to shelter entrances.

The trade-off between storing water and constructing water wells has been analyzed by Guy B. Panero, Inc. (1974) and Jensen (1967). It was found that shallow wells provide a viable economic alternative to storage for shelters holding 1000 people or more, and that deeper wells (400 ft or more in depth) become economical for shelter populations larger than 6000 people. This is only true, of course, if reliable aquifers, which carry adequate amounts of water, underlie the area near the shelter.

Internal water recycle has been investigated by W. L. Badger and Associates (1962) and was found to be uncompetitive with conventional schemes for water supply. Water supplies in containers, particularly cubical containers, can be useful for providing additional, temporary radiation shielding for the shelter -- particularly for the entryways. The use of such moveable shielding can significantly reduce the cost of an entranceway.

An important aspect of the water supply problem which has not been mentioned is the importance of locating or establishing a supplemental water supply outside the shelter. When the shelter water supply is exhausted and the radiation levels have decayed to the point where brief excursions from the shelter can be made, additional water can be brought into the shelter from such an external source. It would be very prudent to consider this problem in the course of shelter planning. Several alternative potential sources of water should be identified; transportation (foot, bicycle, or automobile) for moving water to the shelter should also be considered.

4.7 SANITATION

The removal of human wastes and provision for minimal personal cleanliness is an obvious health, aesthetic, and morale problem in shelters (Blohm, 1965; Des Rosiers, 1962, 1965). It is obvious that inadequate sanitation facilities would facilitate the spread of enteric diseases, although the seriousness of this as a threat to life is doubted by Kopala (1967). He found the major problem to be psychosomatic diarrhea due to mental tension and stated that "there is no evidence that acute gastrointestinal disorders in closed ecosystems present a major problem;" nevertheless, a potential health hazard exists and should be considered in shelter planning.

There has never been a shelter occupancy test with a population which has been exposed to enough radiation to degrade their immune system. It is to be expected that many shelter occupants in an all-out nuclear war could have acquired radiation doses of 100 to 200 rem. Minor enteric diseases might be fatal to this population.

Measurements of human waste disposal requirements range from 0.13 to 0.6 gallons per day, with a recommendation of 0.45 for shelter planning purposes (Martin and Latham, 1963). The state--of-the-art technology for human waste disposal in public, American shelters today is the dual-use 17.5-gal water container. The container, when emptied of drinking water, can be fitted with a toilet seat and used as a commode until nearly full (with the addition of chemicals to prevent bacterial action). It could then be sealed and stored either in the shelter or just outside the shelter. In all tests, the removable waste container has proven to be by far the most satisfactory means of disposing human waste. Kapil (1968) reports on the development of low-cost sanitary containers as alternatives to the water container for shelters with some alternative source of water.

The use of a waste vault or tank equipped with a diaphragm pump to periodically pump the waste outside the shelter is an obvious technological approach which has been tried several times

(Hahl, 1962; Des Rosiers, 1965). Problems have developed with leaks from the fittings on the tank and the pump and with solids jamming the pump. This system apparently cannot be made to work unless a separate provision is made for the disposal of sanitary napkins and toilet tissue. The solids will work their way through the screens on the intake of the diaphragm pumps and jam the check valves.

Flush toilets, while a highly aesthetic solution to the problem, are completely unacceptable due to their very large water consumption -- nearly 4 gallons for each flush (Caughron and Chung, 1967). There is a prospect of using a marine or recreational vehicle commode and a recirculating fluid system (Caughron and Chung, 1967); however, additional work is needed to determine the adaptability of modern marine and recreational vehicle sanitary technology to shelter sanitation. The subject of sanitation is also reviewed in Wright, Chessin, Laney, and Cox, (1982); Martin and Latham, (1963); and Nehlsen (1955).

4.8 SHELTER LIGHTING

Lighting is highly desirable in shelters. In addition to improving morale and preventing vertigo on the part of susceptible people, it makes the handling of food and water vastly easier and more efficient and makes a very important contribution to maintaining adequate sanitation.

The most comprehensive study of required illumination and costs was published by Smith and Wendel (1963). They found that lighting levels as low as one-quarter footcandle could be used for simple existence requirements in shelter (office desk work requires 40 to 100 footcandles; normal daylight is approximately 1000 footcandles). They found that incandescent and fluorescent lamps are usable sources of illumination for all shelter sizes, with fluorescents having a cost advantage in 500- and 2000-space shelters. Approximately 80% of the cost of the lighting systems which they examined went into the motor and generator.

Neveril and Behls (1967) proposed a pedal-powered, 50-watt generator for shelter illumination. They estimated cost of the power system plus bulbs at about \$90 in 1967 (\$317 in 1985). Their co-workers, Jago and Kapil (1970), refined the design to eliminate the roller chain between the pedals and the generator and replaced it with a V-belt. The cost was in the vicinity of \$100 in 1970 (\$289 in 1985). If one assumes a 40-watt fluorescent bulb producing 81 lumens per watt, one can illuminate 1600 ft^2 of shelter to an intensity of one lumen per ft^2 (1 footcandle). This system can produce light for a shelter population of 160 people. Table 4.3 compares the different illumination options to provide one footcandle of illumination in shelters of 50, 500, and 2000 people. The costs per occupant are corrected to 1985 dollars.

Table 4.3. Comparative cost per space of shelter illumination methods (1985 $)

Illumination method	Cost per shelter space (1985 $) for		
	50-person shelter	500-person shelter	2000-person shelter
Propane	$30.56	--	--
Fluorescent bulbs & motor generator	$62.80	$7.92	$3.28
Incandescent bulbs & motor generator	$62.32	$9.80	$6.16
Fluorescent bulbs & pedal generator	$ 5.78	$1.80	$1.80

Smith and Wendel (1963) suggested a concept for illuminating shelter during the daytime with sunlight. This was carried further by Smith (1963) who developed and tested a prototype unit. The illuminator consisted of a periscope, which was 1 ft. square, and contained two 45° mirrors. The periscope would face due north. Directly in front of the periscope was mounted a heliostat, consisting of a 2-ft.-square mirror mounted on a frame containing adjustments for azimuth and elevation of the mirror. These were controlled from inside the shelter by ropes through a conduit to pulleys on the heliostat assembly. Smith also recommended a fourth mirror in the system that would deflect the column of light entering the shelter directly upward onto a diffuser mounted on the shelter ceiling. He claimed illumination intensity inside the shelter equal to four 100-watt bulbs when the external sunlight intensity was 7800 lumens per ft^2. A prototype design was built for $440 in 1963 ($1760 in 1985).

It is obvious that a significant cost reduction can be made in this concept with a little ingenuity. For underground shelters, mounting the heliostat support shaft directly through the roof would permit a very simple mechanism for adjustment of elevation and azimuth, controlled by a piece of thin-wall tubing around a wooden dowel. The periscope could serve double-duty as an air intake duct. Very inexpensive plastic mirrors are available or could be improvised from household aluminum foil (bright side out) glued to plywood or other rigid material.

A small, long-burning candle inside a glass jar is a practical, low-cost solution for a small family shelter, provided that enough candles to last for a two-week period are stored in the shelter. For family shelters, the most cost-effective minimal illumination can be provided by improvised oil lamps burning household vegetable oil. The construction details, Fig. 4.20, for these were developed and tested by Kearny (1979). In the tests, these oil lamps also proved to be effective at attracting and then destroying flying insect pests, such as mosquitoes.

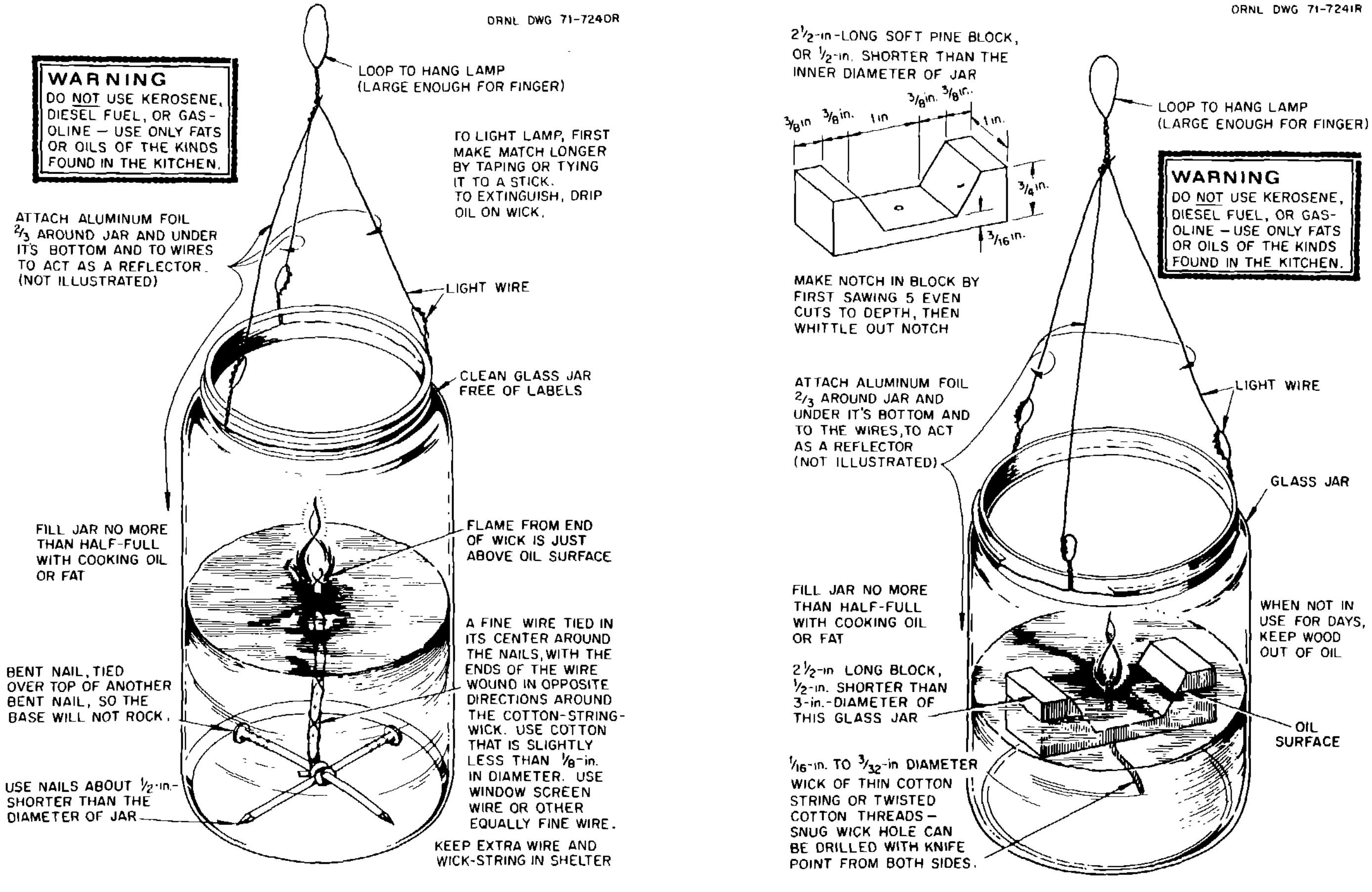
4.9 ELECTRIC POWER

The essential electrical power needs for various shelters are determined primarily by ventilation loads and lighting requirements. Family shelters with manual blowers and a self-contained light source (candles, flashlights, or oil lamps) can manage to operate with very small amounts of electric power. The requirements for a dual-purpose shelter vary with the number of shelter spaces, ranging from a minimum of 1 kW for 50 spaces, to a minimum of 39 kW for 5000 persons (General Electric Company, 1964).

A dual-use shelter would already be supplied with power during peacetime; in crisis use, an auxiliary power system (such as a gasoline- or diesel-powered motor/generator set) would have to be provided. Storage batteries would not be suitable as the primary source of power due to their high initial cost and the large volume requirements for a given capacity (Defense Civil Preparedness Agency, May 1978). However, a storage battery system could be used to start an auxiliary system. Storage batteries, at least the automotive (lead-acid) type, present a hazard from the chemicals which they contain. Liquid fuels for motor/generators present their own hazards, particularly when their vapors are confined within closed structures such as shelters.

In a family shelter with a floor area of at least 100 ft^2, a single 75-watt incandescent bulb should provide adequate illumination. Based upon the absolute minimum ventilation requirements (3 cubic feet of air per minute for each shelter occupant), a blower with a 1/8-horsepower motor will supply about 30 cubic feet of air per minute and will consume about 250 watts while running (500 watts are required to start such a motor). Therefore, the total minimum power requirement is on the order of 575 watts for a small family shelter (General Electric Company, 1964). Manual ventilation and self-contained lighting will reduce this requirement significantly.

The General Electric Company (1964) studied the feasibility of producing electric power from improvised assemblies of commonly



WIRE-STIFFENED-WICK LAMP

FLOATING WICK LAMP

Fig. 4.20. Safe expedient lamps.

available equipment (such as electrolytic batteries made from aluminum pie pans, copper scrub brushes, and household chemicals). They also found that charging automotive batteries was not practical with pedal-operated units; the small power output of these units limited the useful charging period to about five minutes of hard pedaling. The most readily available, improvised power source for shelter use consisted of a 12-volt, automotive generator or alternator driven by a gasoline lawnmower engine; in tests, such a unit developed a continuous output of about 30 amps.

Low-cost portable generators which are suitable for shelter use are commercially available in the United States. Except for the hazards presented by storing and handling the liquid fuels for these units, they appear to be a satisfactory solution to the problems of generating electric power in the shelter. Lauck, Overbye, and Hart (1964) and Trayser, Flanigan, and Talbert (1964) indicate that such motor/generator systems should be periodically exercised (for approximately one-half hour every week) in order to verify their state of readiness. Trayser, Heir, and Ellis (1967) state that the acceptable storage life of gasoline is 2 to 5 years (depending on storage conditions), while diesel fuel can be stored up to 10 years.

For additional information on electric power generation for shelters, the following references are suggested: Fabuss and Borsanyi (1964); Hopwood (1982); Lauck and Overbye (1963); Streuli (1982).

4.10 SHELTER SPACE REQUIREMENTS AND OVERCROWDING

The recommended, "standard" size for U.S. shelters is 10 ft^2 of floor space per person. This number was developed from careful consideration of theoretical studies and habitability exercises (see Section 5.2); it is also close to the minimum floor area occupied by a recumbent person. By comparison, the area of a full-size mattress is about 28 ft^2--for occupancy by two people. The Swiss also specify approximately 10 ft^2 per occupant in their shelter designs (Federal Office of Civil Defense, 1983).

Hannifan, Blockley, Mitchell, and Strudwick (1963) analyzed the physiological and psychological factors which limit survival in overcrowded shelters. They concluded that response to the thermal environment would be the variable of greatest concern. Keeping an overcrowded shelter population cool might require as much as 6 to 12 quarts of water daily per occupant due to individual differences in the heat acclimatization. A minimum effective air velocity of 50 to 75 ft per minute, impinging upon the bodies of the shelter occupants, was recommended.

Krupka (1964b) agrees that physiological stress (heat, humidity, lack of water, sanitation, etc.) rather than psychological stress is the limiting factor in shelter overcrowding. Furthermore, he suggests that 150% overcrowding (i.e., 5 persons in every 2 shelter spaces) can be tolerated for extended periods of time; a value of 3 ft^2 per occupant is given as the lower limit of acceptable, extended overcrowding densities. Krupka estimates a 5 to 10% increase in the cost of 30-psi shelters in order to handle a 150% shelter occupancy (with well-water cooling already installed).

Biderman, Louria, and Bacchus (1963) have presented an excellent review of historical incidents which involved overcrowded quarters--slave ships, prisoner-of-war camps, troop transport, concentration camps, and crowded slum housing. They found that, in regard to survival in an overcrowded space, physical crowding has only an interdependent relationship with other variables: environmental, structural, temporal, psychological, and social. They suggest that morale encourages survival; physical density is not a good measure of the potential effectof overcrowding on survival. African slaves, packed to a density of 1.3 ft^2 per person aboard trade ships, routinely survived a 5- to 6-week voyage; although, a 15% mortality rate was not uncommon. A New York subway car, packed to its maximum legal capacity (seating and standing room), provides only 2.3 ft^2 per person; London basement shelters in World War II were typically occupied at a density of 4 ft^2 per person.

In regard to the design of a national system of shelters, overcrowding must be given serious consideration: it may result in overall cost reductions, it could mean the purchase of harder systems if limited funds are available, and it might provide large quantities of shelter space in the fastest time.

4.11 SHELTER FURNISHINGS

After an adequate level of protection has been provided in a shelter, the comfort of the shelter occupants is of primary concern. Sleeping and seating facilities have proven to cause major discomfort in actual shelter habitability tests (see Section 5.2).

Sleeping facilities have been given the most attention in previous research into shelter furnishings (Gates and Schwaner, 1962; Havers, Monk, and Koeller, 1965; Kearny, March 1966, 1979; Rathmann, December 1970). Bunks which are tiered, up to five high, make the most efficient use of shelter space for sleeping. If such bunks are designed so as to be quickly disassembled, then they can be easily converted into seating or eating areas during the daytime hours. Individual bunks with a size of 24 by 75 in. and with a 20-in. vertical clearance between them have been shown to be an acceptable minimum arrangement. However, Rathmann

(December 1979) has shown that there may be problems in successfully ventilating the occupants of such high-density bunks.

Kearny (March 1966) has presented the most ingenious solution to the provision of sleeping and seating facilities; he has suggested the use of hammocks. The arrangement of hammocks can be very flexible; in one test, Kearny fit 8 adults (in hammocks)--with additional room for two more people on the floor--into a 7.5-ft length of an 8-ft-diam concrete pipe shelter. Hammocks also provide some protection from ground shock and shelter motion due to the damping effect of their suspension cords. Kearny (1979) has also indicated how these same hammocks can be used for seating purposes.

Norman Steuer Associates (1963) has presented low-cost designs for chairs, tables, and benches which were field tested in actual shelter habitability experiments. For additional information on shelter furnishings, the following references are suggested: Herzog, Wells, and Cromartie (1963); IIT Research Institute (June 1964); Kapil (1972); Meier, Smith, and Gaynor (1968).

5. SHELTER TESTING

Shelters can be tested for blast hardness of the shelter structure and its components, radiation protection, habitability, constructability, and cost. By far the most common type of testing has dealt with blast hardness; measurements of radiation protection were almost as common in the early nuclear weapon testing program.

Relatively few habitability tests have been run on blast and fallout shelters, and even fewer tests have been run on the constructability of shelters. Reinforced concrete design and construction is considered a well-developed technology with routine design procedures and well-defined cost-estimating procedures. Constructability experiments have been run only for expedient shelter.

5.1 WEAPON EFFECTS TESTING

The inclusion of shelters in actual nuclear weapons tests began in 1951 and continued through 1958. Beck (1969) and Brode (1980) have presented excellent reviews of these tests. The cessation of atmospheric nuclear weapons testing by the United States and the Soviet Union was institutionalized by the Test Ban Treaty of 1963. In the 1960s, testing was begun by both Canada and the United States with large high-explosive charges to simulate nuclear weapons. Much useful information has been obtained from these tests; summaries are presented below.

5.1.1 Nuclear Testing

Testing of shelters against real nuclear weapons has many advantages, not the least of which is exposure to a real initial radiation threat and to full-duration overpressure and ground motion. For surface bursts, fallout protection factors can be measured also.

The disadvantage to nuclear testing, aside from the fact that it is prohibited by treaty, is that shelter tests were very much subordinated to the weapons development program. The yield and time schedule of the preparations were determined exclusively for the convenience of weapons development. Occasionally, significant deviations from the expected yield were encountered. In most cases, the deviations were in the direction of a lower-than-expected yield, although the BRAVO shot of OPERATION CASTLE was a spectacular deviation in the other direction.

All of the shelter tests that were conducted by the United States during actual nuclear detonations are summarized in Nuclear Weapons Effects Tests of Blast-type Shelters by Christian Beck (1969). This volume is a compendium of all of the individual weapons test reports on blast shelters.

The first documented tests of U.S. shelters occurred in the BUSTER-JANGLE test series in Nevada during October and November of 1951. In these tests some 29 shelters were built along an arc about 1200 ft from the designated ground zeros of three low-kiloton airbursts. The shelters were wood-lined covered trenches, covered metal arches, and basement lean-to shelters. Instrumentation was very crude. The tests showed that very low-cost structures, when covered with soil, could resist nuclear weapons effects (Flynn, 1952). Tests of buried concrete and steel pipe showed that economical structures could be built to resist a great deal of blast pressure and to provide significant radiation protection (Corsbie, 1952).

In the Nevada TUMBLER-SNAPPER series in April through June 1952, "hasty air-raid shelters" were tested; these were unshored, covered trenches exposed to low-kiloton nuclear weapons. They provided good radiation protection, but their ability to withstand destruction depended on the cohesiveness of the original soil (Murdock, 1953).

In the UPSHOT-KNOTHOLE series in Nevada during early 1953, instrumentation began to become more sophisticated, producing pressure-time traces. This series included a test of blast effects on entrances and air intakes, including blast valves (Sinnamon, Austin, and Newmark, 1955). Newmark and Sinnamon (1954) carried out some of the first tests on dynamic soil stress in the vicinity of a buried structure. The structure had a very stiff roof and showed no earth-arching. They observed greatly reduced pressure on the walls of the structure and a pressure distribution over the floor comparable to that on the roof.

In this same test series, the Navy tested a bermed 25-ft-span by 48-ft-long steel arch personnel shelter with 3 ft of earth cover at 10.8 psi. The entryway was blown into the shelter by pressure coming down the entrance tunnel. However, the main part of the structure survived with only minor distortion. A structure of similar size, assembled from precast concrete panels, survived with similar, minor damage (Longmire, 1955).

Eight outdoor and four indoor home shelters proposed by the Federal Civil Defense Administration for protection against radiation and blast effects were also tested. The overpressures were about one-half those anticipated, resulting in no damage to any of the shelters. The shelters included a covered trench with concrete liner, a wood-covered trench, a concrete pipe, a block wall, and a wooden basement lean-to. The shelter closest to ground zero survived 25 psi (Brynes, 1953).

Also in the UPSHOT-KNOTHOLE test series, Roberts, White, and Chiffelle (1953) obtained some of the first information on the biological effects of nuclear weapons upon animals and dummies in group shelters.

OPERATION CASTLE in 1954 was a series of high-yield explosions in the Pacific at Bikini Atoll, involving tests of the early thermonuclear weapons (hydrogen bombs). Tests of civilian structures were reported in this series; however, the first shot of the series, BRAVO, had a yield of 14.5 megatons when only a 6-megaton yield was anticipated. The high yield resulted in unanticipated high pressures which caused destruction of structures not directly involved with the tests; failure of protective structures for camera mounts, among other things, were observed (Christensen, 1955).

In OPERATION TEAPOT, in 1955 at the Nevada test site, attempts to get quantitative information on earth-arching using a steel beam roof on an underground shelter were again unsuccessful, probably due to the fact that the structure was too rigid (Woodring, Sinnamon, and Newmark, 1957). Further tests of 25-ft-span by 48-ft-long steel arch shelters were carried out. There were two full-scale structures and three steel and three aluminum quarter-scale models in the test. The buildings collapsed at 30 psi overpressure (approximately 200 psi dynamic pressure). The buildings were bermed aboveground and hence were sensitive to the dynamic pressure (Vaile and Mills, 1956).

Two buried, concrete box shelters with 12- to 24-in. walls were subjected to the effects of an underground nuclear explosion in this series. Both structures survived the blast; although, one was only 55 ft from the lip of the crater and was displaced almost 2 ft vertically and 4 ft radially from ground zero (Sinnamon, Woodring, Newmark, and Matsuda, 1957).

A variety of family shelters were tested in the APPLE-1 and APPLE-2 shots of this series. They included basement exit shelters, masonry shelters, poured-in-place concrete shelters, a basement lean-to, a basement concrete room, a concrete bathroom, and what was called a utility shelter (an aboveground, unbermed, unshielded, cubicle). In general, the underground shelters fared fairly well. The basement exit shelters suffered moderate-to-severe damage depending on the number and size of the shelter openings. The indoor shelters survived quite well at 5 psi despite the fact that the house around them was destroyed (Vortman, 1957).

During the APPLE-2 shot, ten typical American residential structures (houses) of wood, brick, lightweight reinforced concrete block, and lightweight precast concrete slabs were tested. Both one- and two-story structures were subjected to a 29-kT explosion. The two-story brick house and the one-story frame rancher were completely destroyed at the 5 psi overpressure location. The other structures sustained considerable damage, even at overpressures as low as 2 psi (Randall, 1961).

Also, in OPERATION TEAPOT a variety of animals were exposed to blast overpressure and thermal radiation in open shelters. This work contributed much to the understanding of blast biology; it demonstrated the necessity for having doors on blast shelters (White, C.S., et al., 1956).

OPERATION PLUMBBOB took place in Nevada during the summer of 1957. Progressively more sophisticated varieties of shelters were tested in this series. Four concrete arch structures with 16-ft spans and wall thicknesses of 8 in. were placed at expected 50, 100, and 200 psi levels from a 36-kT tower shot. The actual overpressures received were 56, 124, and 199 psi. All structures survived, with some cracking in the structure at the 199-psi pressure level. These structures were placed with the top of the crown 4 ft below ground level so they were effectively protected against drag forces (Flathau, Breckenridge, and Wiehle, 1959).

In the same shot there were tests of 10-gauge corrugated steel cattle passes, 10-gauge corrugated steel circular pipe, and circular concrete sewer pipe. The structures were buried at depths of 5 to 10 ft. Pressures as high as 149 psi and gamma neutron doses in excess of 100,000 R were experienced aboveground at the shelter location; however, there was negligible deflection in all of the shelters and negligible radiation recorded inside (Albright, LeDoux, and Mitchell, 1960).

Two types of 25-ft-span by 48-ft-long corrugated steel arches were also tested in the PLUMBBOB Series. One was a 10-gauge corrugated steel arch, the other was a corrugated steel arch with reinforcing I-beam ribs. Both structures were buried with the crown 5 ft below the original grade. They respectively survived 60 and 100 psi incident pressure (Albright, Beck, LeDoux, and Mitchell, 1961). In another test, a 7-ft-diam, 10-gauge, galvanized, multiplate corrugated culvert buried with 10 ft of earth cover survived a 245 psi incident overpressure. The lack of deformation indicates that it would have survived a much higher overpressure (Williamson and Huff, 1961).

During OPERATION PLUMBBOB, Bultman, Sevin, and Schiffman performed tests on seven existing structures which were left from previous nuclear tests. The primary objective of these tests was to determine the reliability of damage prediction schemes; however, a secondary finding was more important with respect to shelter design. When testing the same underground structures used by Newmark and Sinnamon (1954) in the UPSHOT-KNOTHOLE series, a significant attenuation of effective vertical earth pressure was observed within the first few feet of depth. This was, at last, a clear indication that increasing the depth of burial would provide greater protection from blast loading for buried structures.

In another test, an experiment was done in which a buried vertical concrete cylinder was protected from ground motion by surrounding it with square glass bottles. A reduction of peak acceleration by 75% was observed (Vaile, 1960).

A 7500-ft^2 underground parking garage equipped with a 4-ft-thick rolling door was tested at approximately 40 psi. There was no damage to the garage or to the door. The retaining wall at the end of the entrance ramp was damaged due to 180 psi reflected pressure at that point and to possible pressure amplification in the reentrant corner (Cohen, Laing, and Bottenhofer, September 1962).

The FCDA Family Shelter Mark I was tested at 30, 48, and 65 psi; this shelter was a rectangular concrete box with a "Z" shaped entryway and was designed for 30 psi. There was no damage to the shelter structure at 65 psi. The ventilation pipes were bent over at right angles, thus rendering them inoperative. FitzSimons (1957) estimated that the shelter would have taken considerably more overpressure.

FitzSimons (1958) also tested several industrial doors designed for blast resistance to reflected pressures of 9 to 17 psi. The door types included steel plate, cellular steel, wood plank, hollow plywood, and solid plywood. Only the hollow plywood door failed structurally. The door hardware (i.e., hinges and latches) was found to be the weak point for some of the door designs; the "rebound" forces on the hinges and latches were found to be one-half the positive blast forces on the door.

A concrete and steel bank vault was tested in the PLUMBBOB series at more than 300 psi. The structural integrity of the vault was maintained; although, an outer layer of reinforcing steel was stripped away on one side (Cohen, Laing, and Bottenhofer, May 1962).

A cylindrical concrete personnel shelter developed by the French was tested at 118 and 132 psi. Although superficial damage was done to the structure, radiation protection of the occupants would have been adequate. The intake and exhaust stacks were sheared off (Cohen and Dobbs, 1960). A similar test was run on rectangular buried reinforced concrete and circular reinforced concrete shelters designed by the Federal Republic of Germany. All structures performed as expected (Cohen and Bottenhoffer, 1962).

OPERATION PLUMBBOB also provided an opportunity to test shelter ventilation systems. Dennis, Billings, and Silverman (1962) evaluated the effects of blast on filtration devices and typical gas cleaning equipment. White, Wetherbe, and Goldizen (1957) investigated 18 underground structures for the occurrence of posttest dust. They found that, even in closed shelters, annoying or irritating dust could be produced from the interior surfaces of the shelter as it responded to the blast loading.

OPERATION HARDTACK in 1958 was the last atmospheric nuclear test series at which there was documented testing of civilian shelters. Phase I, employing large-yield weapons, was carried out in the Pacific. The 25-ft-span by 48-ft-long, 10-gauge corrugated metal arches which were tested successfully in the PLUMBBOB series were tested again at the Pacific test site. Two important modifications were made. Due to the high water table, the arches were constructed at grade level and then covered with an earthen berm. The second and more crucial difference is that the berm was composed of coral sand containing large numbers of small crushable sea shells. The arches were tested at pressures ranging from 78 to 180 psi. All failed catastrophically (LeDoux and Rush, 1961).

The OCDM family fallout shelter was tested in Phase II of OPERATION HARDTACK at the Nevada test site. It was expected to have only 5 psi blast resistance, but withstood 13.5 psi with no structural damage at all. With over 2 ft of earth cover on the 8-ft-span roof, it could have taken considerably more overpressure (Roembke, 1958b).

Also in OPERATION HARDTACK, Cameron and Huff (June 1962) tested the initial nuclear radiation doses and the accelerations inside four shelters. Initial nuclear radiation doses were found to be higher than those predicted; however, radiation backscatter from the shelter walls and gamma radiation originating from neutron penetration of the concrete structure were not taken into account in the predictions. Measured accelerations inside the structure indicated that the peak horizontal and peak vertical accelerations were about equal; although, both were up to 50% higher than the free-field accelerations.

If one reviews the history of shelter development in nuclear tests over the period of 1951 to 1958, progress is readily apparent. It was quickly learned that protection from initial nuclear radiation was a major problem which dominated the shelter design for low-yield weapons. It was also learned from animal experiments that it is not possible to build an open shelter for nuclear weapons for more than a few psi. Much effort in the civilian shelter development program was directed at keeping costs down. Helpful in this respect was the use of selected unsaturated soil cover to gain earth arching, thereby helping the structure to resist more blast load.

5.1.2 High-Explosive Field Tests

With the negotiation of the Test Ban Treaty in 1963, the Defense Atomic Support Agency, now the Defense Nuclear Agency, turned to high-explosive tests to continue the development of nuclear-resistant military structures and equipment.

An agreement was reached with the Canadian government for U.S. participation in high-explosive field tests which the Canadians had been conducting since the early 1960s. The tests were conducted at Suffield Experiment Station in southern Alberta by the Canadian Defense Research Establishment. A test in 1961 using 100 tons of TNT included experiments with 1/10th-scale concrete slabs at the surface and belowground (Purdie, 1964) and tests at 50 psi of 1/12th-scale concrete structures (Davies, 1963).

The test charge was raised to 500 tons of TNT in OPERATION SNOWBALL, the first large-scale U.S. high-explosive test (General Electric Company--TEMPO, 1965). The test was held in New Mexico in July 1964 and included experiments with buried concrete arches (Palacious and Kennedy, 1967; Sager, 1965). Kennedy (1970) also reported tests on a half-scale, flexible arch shelter in dense sand in OPERATION PRAIRIE FLAT, a 500-ton TNT shot in Canada in the summer of 1968.

OPERATION DIAL PACK, another Canadian test, followed in July 1970. DIAL PACK was a single 500-ton TNT blast. Various shelter types were included in the event: Canadian family blast shelters (Jones, Johnson, and Reid, 1972), concrete arch bunkers (McGrath, 1971), and even a fiberglass blast shelter (Nielsen, 1981).

This test was followed by the U.S. test, MIXED COMPANY, in November 1972. This was a 500-ton, TNT shot with foreign participation from several NATO countries (General Electric Co., 1973a, 1973b). The personnel shelters which were tested included a variety of wooden structures by the Waterways Experiment Station (Ball, 1974) at 15, 30, and 100 psi and also included a 1/2-scale corrugated metal arch. This test was also the first blast test of expedient shelters by the Oak Ridge National Laboratory (Kearny and Chester, 1974).

The DICE THROW event, conducted by the United States in October 1976, was a 600-ton ammonium nitrate-fuel oil (ANFO) explosion. The ammonium nitrate and fuel oil explosive, in addition to costing less than 1/10th as much as TNT, is also a clean explosive which does not cover everything with the black, greasy soot characteristic of TNT shots. Many varieties of expedient shelters were tested by the Oak Ridge National Laboratory in this event, including a Russian small-pole shelter at 53 psi (Kearny and Chester, 1978). It was found that unshored covered trenches, even in the hard desert soil at the test site, collapsed from ground motion at relatively low overpressures. Concepts like the rug-covered trench were abandoned completely. There was participation from NATO countries including tests of shelters from West Germany, Norway, and Sweden (General Electric Co., 1977a, 1977b, 1977c; Watt and Kaufmann, 1978; Watt, Kaufmann, and McVay, 1979; Watt, Zahlmann, and Cole, 1977).

MISER'S BLUFF, a 120-ton ANFO explosion, in June 1978 included tests of buried shelters up to 100 psi. The small pole shelter was tested by Oak Ridge National Laboratory (Kearny, Chester, and York, 1980) and the DONN Corporation tested a corrugated metal shelter at that overpressure (Petras et al., 1979a, 1979b). In this test, West Germany had both a basement shelter and a Swedish design modeled after the Russian small-pole shelter (Strode et al., 1979a, 1979b, 1979c). A test of a Swedish vault shelter was reported by Stephens (1979). In the MISER'S BLUFF test, the Boeing Company demonstrated on a mass scale the ability of earth arching to protect industrial equipment by covering the equipment with bags of aluminum chips and then with a few feet of soil (Strode et al., 1979b).

The MILL RACE Event in September 1981 was a 600-ton ANFO shot which saw further development of expedient hardening and crisis upgrading (Tansley and Zaccor, 1982). There were tests of a timber version of the expedient small-pole shelter, Swedish field fortifications, tests of U.S. military portable shelters, aboveground host area structures, basement structures, and keyworker shelters, as well as utility vaults used as shelters (Reid and Grayson, 1982a, 1982b, 1982c).

The DISTANT RUNNER test series included two 120-ton ANFO explosions in September and October 1981. These events were specifically intended to test aboveground, NATO-type aircraft shelters. Two such structures were subjected to 13 and 17 psi (Bousek, 1982; Flory, 1982; Rooke, 1983).

The DIRECT COURSE test in October 1983 was another 600-ton ANFO test which included further demonstrations of expedient industrial hardening and upgrading of basements (Wilton and Zaccor, 1984). The U. S. Army Corps of Engineers tested an entrance and an improved blast door for shelter for critical workers (Hyde and Kiger, 1984). A buried 1/4-scale corrugated metal shelter was tested at 200 psi; the design of this cylindrical structure offers the potential to greatly reduce fabrication costs of corrugated metal shelters. A 0.080-in-thick membrane door was tested and survived 200 psi (Zimmerman and Chester, 1984). Also tested were corrugated metal closures and high-rise basement shelters (Raska and Grayson, 1985).

The most recent high-explosive test was the MINOR SCALE event held in New Mexico in June 1985. This 4800-ton ANFO explosion simulated the airblast of an 8-kT nuclear weapon; it was the largest planned non-nuclear explosion in history. In addition to experiments on military equipment and structures, a 100-man belowground concrete box shelter was tested by the Army Corps of Engineers as part of the keyworker shelter program. Published results from MINOR SCALE are not yet available.

High-explosive tests, while not producing long duration overpressure or initial nuclear radiation, do offer very large test areas at very little cost. Quarter-scale models can be tested; they provide the response of a full-scale test object to smaller strategic nuclear weapons. However, such tests provide only very short duration overpressures. Objects buried at depths where the travel time of the shock wave in soil from the surface to the test object is comparable to the positive duration of the blast wave will not respond fully to the overpressure. The use of scale models to avoid this difficulty has its own set of problems. Where forces due to gravity are important in stresses on the test object, the object will, again, not respond fully. Reducing the scale of a model has the same effect as reducing the gravitational field on the prototype.

5.1.3 Laboratory Simulation Testing

There are other explosive techniques for simulating nuclear overpressures and durations on test items. To simulate large-yield weapon durations on buried structures, the High Explosive Simulation Technique (HEST) can be used. In this technique the structure is buried, then covered by a cavity containing explosives and a heavy earthern berm. By varying the volume of the cavity, the amount of explosive in it, and the thickness of the earth cover, any combination of weapon yield and overpressure can be simulated (Wampler et al., 1978). This technique suffers from the shortcoming that there is no negative phase of the overpressure, and there is danger of the experiment being damaged by dirt and structural material falling back into the test area.

Shock tubes can be used to apply both overpressure and dynamic (wind) pressure to experimental objects small enough to fit in the tube. Large-diameter shock tubes are in operation at the Ballistic Research Laboratories at Aberdeen Proving Ground, Maryland.

Waterways Experiment Station in Vicksburg, Mississippi, has a number of weapon overpressure simulators. These consist of vertical cylindrical tanks which can be pressurized dynamically with explosives or statically with water. Scale models can be tested in the earth-filled lower section of the tank (Flathau and Balsara, 1978; Guice and Slawson, 1986). Overpressures of several hundred psi and any duration can be obtained in these simulators.

Unlike shock tubes, these simulators do not produce a blast wind or dynamic overpressure on drag-sensitive targets.

High-explosive testing and/or simulation techniques are available which can simulate most of the blast effects of nuclear weapons. Using these techniques, designs can be tested to provide high confidence that a shelter will perform according to design in a nuclear weapons environment. The techniques do not simulate every nuclear weapon effect simultaneously; notably missing are initial nuclear radiation and ground motion of a magnitude equal to that produced by large-yield nuclear weapons. At high overpressures from small weapons, these effects largely control the design. Caution must be exercised to prevent over confidence in high pressure shelter designs simply because they have been tested in high explosive simulations.

For additional information on laboratory testing of shelters, the following references are suggested: Albritton and Balsara (1980); Allgood, White, Swalley, and Gill (1963); Bakos (1969); Criswell (1972); Gabrielsen and Wilton (1974); Leskys and Albritton (1968); Walker and Bultman (1984); Willoughby, Wilton, and Gabrielsen (1967, 1969); Wilton and Gabrielsen (1972, 1973); Woodson (1984).

5.2 HABITABILITY TESTING

Habitability testing of actual shelters has been done for three reasons: (1) to conduct engineering evaluations of the shelter and its various systems, (2) to conduct psychological evaluations of shelter occupants and shelter managers during actual in-shelter tests, and (3) to provide information on adequate ventilation rates inside shelters. The first two categories have involved actual, long-term (up to two weeks) occupancy experiments. The third category of tests has largely been done in unoccupied shelters. Wright, Chessin, Laney, and Cox (1982) have attempted to summarize the findings of these shelter habitability studies. A more detailed description of such experiments is given in this section.

5.2.1 Engineering Aspects of Habitability

Shelter occupancy experiments began in 1959 (Vernon, 1959), when Princeton University made the first attempt to determine whether or not a family could remain confined in a shelter for a period of 14 days and to determine the nature and gravity of any problems associated with shelter occupancy. The five-member family remained in an 8-ft by 9-ft basement fallout shelter for the first two weeks of August 1959. The shelter was stocked with food, water, a manual blower, and a chemical toilet. Although the temperature inside the shelter reached 79°F, the family was able to remain comfortable by operating the blower for approximately five minutes every half hour during the period when they were awake. The study was successful in that it clearly indicated that this particular family was capable of easily withstanding the full 14 days of shelter confinement; no major problems developed.

Altman, Smith, Meyers, McKenna, and Bryson (1961) of the American Institutes for Research (AIR) followed several, brief pilot studies with a set of four experiments, each with a 30-person group occupying a simulated shelter. Three of these occupancy tests were each run for a duration of one week; the fourth lasted two weeks. The major experimental variables were the shelter temperature and the presence or absence of a trained shelter manager. The shelter occupants were paid volunteers of both sexes, ranging in age from 7 to 72. The simulated shelter was approximately 12 by 20 ft with an actual floor area of 242 ft^2 (8 ft^2 for each occupant).

The AIR tests measured the tolerance of shelter occupants to increases in the "effective temperature" of the shelter. The "effective temperature" is that temperature of air at 100% relative humidity which causes the same sensation of warmth or cold to the human body as does the existing room temperature and humidity level. In one of the AIR tests, the effective temperature climbed to 85°F, a level which the investigators found to be tolerable but near the threshold of intolerance. At this temperature, the shelter occupants exhibited profuse perspiration, reduction of activity, lack of concentration, headaches, nausea, and elevated body temperatures. The investigators found that "personal effectiveness and shelter organization would be seriously impaired by higher temperatures for a prolonged period."

During the last 20 hours of the two-week AIR test, eleven additional occupants were admitted to the shelter in order to simulate overcrowding. The 30 bunks, which could be disassembled for increased daytime floor space, provided adequate sleeping space for all of the additional shelter occupants. Even with this increased number of occupants (41 total occupants at 6 ft^2 per person), no major problems or conflicts developed.

The U.S. Navy conducted several shelter occupancy tests between 1959 and 1963. Each of these was an "engineering evaluation" of shelter equipment and procedures. Two shelters were used: one in Camp Parks, California, and the other in Bethesda, Maryland. The shelter design used in these tests was the same as the buried, corrugated-metal, steel arch which had been tested in the OPERATION PLUMBBOB nuclear test series of 1957 (Albright, Beck, LeDoux, and Mitchell, 1961). The 25-ft by 48-ft shelters were designed for occupancy by 100 persons at 12 ft^2 per person. The shelters were equipped with plumbing for the drinking water and for the toilets and also with an electric generator system for powering the lighting system and the ventilation blower.

Four tests were conducted by the U.S. Naval Radiological Defense Laboratory (USNRDL) using the Camp Parks shelter. In October 1959, 100 male volunteers (inmates from a minimum security prison) occupied the shelter for two weeks (Goldbeck and Newman, 1960). The shelter temperature ranged from 71 to 81°F. A diurnal variation of temperature was observed inside the shelter; the ventilation blower had to be shut off at night to retain warmth in the shelter. Because only 50 of the occupants could be seated at one time, insufficient seating space was a major problem. In December 1959, the second Camp Parks test also used 100 male inmates as shelter occupants (Strope, Etter, Goldbeck, Hieskell, and Sheard, 1960). No problems were observed during this two-week trial; the mean effective shelter temperature was about 70°F.

In the USNRDL test of July 1960, 100 men occupied the shelter for 100 hours (Strope et. al, 1960). The outdoor temperature reached a maximum of 93°F, but the shelter never exceeded an effective temperature of 81°F. Average daily water consumption was about 3 quarts per person. The investigators reported that the high temperatures seemed to have no effect on the activity of the occupants during this short-duration test. A set of low-cost, fiberboard furniture was included in the test; the resulting wear on this furniture provided insights into better designs (Norman Steuer Associates, 1963).

In the fourth and last Camp Parks test, a mix of men, women, and children occupied the shelter (Strope, Etter, Schultze, and Pond, 1962). These 99 occupants were approximately 50% male and 50% female, with each of these groups further subdivided into 50% adult and 50% children. The largest family unit was seven persons. Ages ranged from 3 months to 68 years. They occupied the shelter for 48 hours in November 1960. The short duration of this test was determined from the observation that, in earlier tests, most shelter problems developed within 48 to 72 hours after the shelter was occupied. Outdoor temperatures ranged between 40 and 63°F, while the effective temperature inside the shelter varied from 66 to 76°F. Average daily water consumption was 2.5 quarts per occupant. Problems with the bunk design were encountered, and a new design was developed.

The conclusions drawn from the USNRDL Camp Parks experiments were that the capacity of the shelter could be increased by up to 100% without imposing serious hardships for the shelter occupants. With 200 occupants inside such a shelter, the floor space per occupant would become 6 ft^2. Restricted use of water was the number one complaint in these tests; lack of space (crowding) and excessive noise were the next two areas of discomfort.

During 1962, the Navy conducted both winter trials (Ramskill et al., 1962) and summer trials (Bogardus, 1968) in the Bethesda, Maryland, shelter. Each occupancy test lasted for two weeks and involved 100 male Navy volunteers who had been psychologically and physically screened for these tests. Only 50 bunks were provided for the 100 men; sleeping was accomplished in shifts.

The Navy winter trials were conducted in February 1962. Despite the fact that outdoor temperatures were in the range of 12 to 55°F and that the shelter had no artificial heating, the temperature inside the shelter was maintained at 70 to 80°F by adjusting the flow rate of the blower. The blower used in this test had a capacity of 600 cubic feet per minute. The average daily water consumption of each shelter occupant was slightly less than 2 quarts per day. No major problems developed during this test.

For the Navy summer trials in August 1962, the blower capacity was increased to 1200 cubic feet per minute due to anticipated problems with cooling the shelter. This still did not alleviate the problems associated with an 85°F effective temperature during the first week and 80°F during the second week. The average daily water consumption of the shelter occupants was 3 quarts per day. The investigators concluded that it was highly improbable that the shelter occupants could have survived a second week with an 85°F effective temperature; the men's bodies were constantly wet from perspiration. This constant wetness also applied to the men's bunks which never dried out during the duration of the test. The rough canvas of the wet bunks aggravated the heat rash and other medical problems developed by the occupants. One shelter occupant failed to complete the test due to heat-related problems; the attendant medical officer handled similar problems for five other occupants.

The last of the Navy occupancy tests occurred in May 1963 (Ross, Trumbull, and Williams, 1965). The unique character of this test was that it was conducted as an impromptu exercise; previous occupancy experiments had used volunteers who had been carefully screened before each test. The 1963 Navy test included Navy officers who were involved in continuing education seminars at the Naval Medical Center. Thirty-four men were taken on a tour of the same shelter used in the 1962 Navy summer and winter trials (described above). At that time, it was announced that these men were to be voluntarily confined for an unknown duration under simulated emergency conditions as part of a shelter occupancy experiment. The men were given the chance to refuse to participate; however, all 34 remained in the shelter. The simulation lasted four and one-half days. The outdoor air temperature remained between 5 and 10°F, but the shelter temperature was 60 to 70°F; many of the shelter occupants complained of discomfort from the cold. The concrete floor of the shelter remained very damp for the duration of their stay. No major problems developed during this short test.

The Navy tests identified several areas of shelter living which required minor adjustment on the part of the shelter occupants. Psychologically, the most discomfort during the occupancy tests was caused by lack of water for washing (hygiene), temperature and humidity, lack of privacy (crowding), and noise.

All of the above tests were conducted inside existing shelters, many of which had modern plumbing connections, electric power, and operating toilets. The only extremely austere occupancy tests of shelters were conducted by the Oak Ridge National Laboratory (Kearny, 1976, 1979) as part of the expedient shelter study. Families were given instructions on how to build and equip an expedient shelter (See Section 7.3); they were paid for their labor, and in addition, they received a bonus payment if they actually spent the night inside their shelter. The longest period of occupancy was recorded for a family of six who constructed a 3.5-ft-wide by 4.5-ft-high by 16.5-ft-long, log-covered trench shelter and then occupied it continuously for 77 hours (a four-night stay). Although the family had only a limited food and water supply, a chemical toilet, and no electric power, they experienced no occupancy problems.

5.2.2 Psychological Aspects of Habitability

The two most significant and extensive studies on the psychological aspects of shelter occupancy were conducted by Collins and Bend (1966, 1968) and by the University of Georgia (Hammes, 1963a, 1963b, 1964, 1965; Hammes and Ahearn, 1966, 1967; Hammes, Ahearn, and Foughner, 1968). Collins and Bend conducted a mail survey of people who had participated in shelter occupancy exercises as part of a shelter management training course which they took through the Civil Defense University Extension Program. This program involved 50 different colleges throughout the country; 60 instructors and 1320 students responded to the survey. The size of each group of shelter occupants ranged from 16 to 30 people; their ages ranged from 20 to 50. Only a few of these occupancy experiments lasted for more than one day; however, more than one-third were overnight stays. Almost all of the tests were conducted in Federally marked fallout shelters. Among other findings, the survey responses indicated that five major factors affected shelter living the most: the inability to sleep, the lack of privacy, the lack of physical activity or exercise, the temperature and humidity inside the shelter, and the unavailability of seating space (overcrowding).

The University of Georgia studies are significant, not only for the large number of total participants, but also for an orchestrated effort to duplicate the U.S. census population statistics (sex, race, age, etc.) among the shelter occupants. Twelve community shelter occupancy experiments were conducted between 1962 and 1967. Hammes, Ahearn, and Foughner (1968) summarize the findings. The size of the shelter groups ranged from 30 to over 10; the ages were from 6 months to 79 years. The longest tests lasted two weeks; the shortest were weekend stays. Both winter and summer tests were included. In two of the tests the available shelter floor space was 6 ft^2 per person; the floor space never exceeded 10 ft^2 per person.

Over 3500 people participated in the twelve University of Georgia tests. These people were paid volunteers, but one remarkable finding of the experiments was the rather large number of participants who elected not to stay in the shelter for the duration of the test. About 10% (344 persons) of the 3510 total shelter occupants did not complete the tests; the investigators called these people "defectors." Unbearable hot humid conditions inside the shelter provided the motivation for several of these defectors, particularly for the 20% (62 people) who left a June 1965 test which involved some 300 occupants. The highest defection rate, 40% occurred in a July 1963 test involving thirty, preteen school children. Shelterees who did endure the confinement period listed lack of water for washing (hygiene) as the primary discomfort. Other major complaints were difficulty with sleeping, temperature, inadequate sanitation facilities (toilets), and lack of space. Tolerance for continued confinement ranged, in terms of median data, from two to seven days.

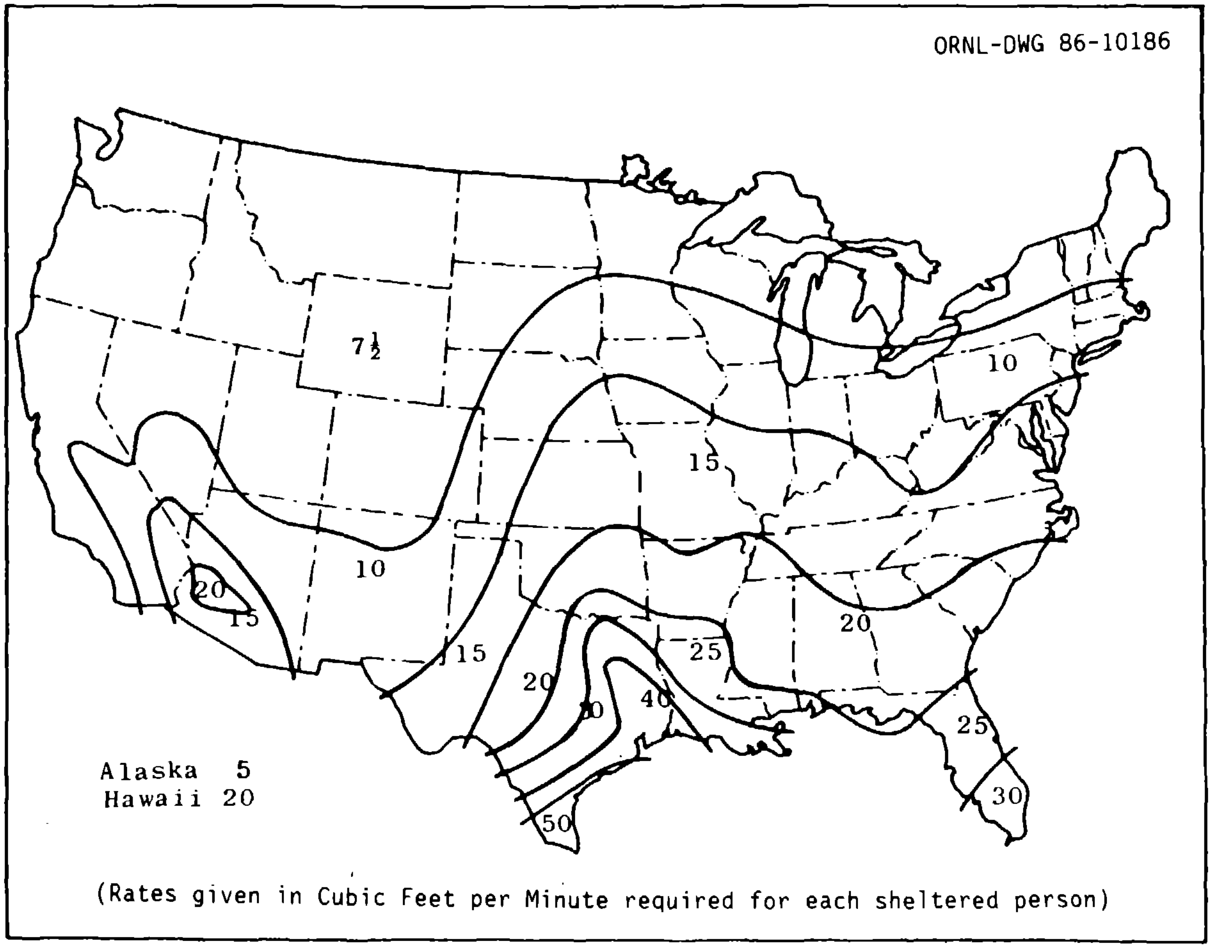
5.2.3 Ventilation Tests

One of the obvious conclusions from the above set of shelter occupancy experiments is the intolerance of shelterees to hot, humid conditions. For shelters containing more than a few people, the heat and moisture given off by each occupant becomes an important consideration with respect to keeping those occupants cool. In warm weather the temperature and humidity in the shelter can reach levels causing heat prostration and even death. In recognition of this fact, a great deal of research has been conducted to determine the ventilation requirements in both aboveground and belowground shelters (Baschiere and Lokmanhekim, 1964; Baschiere, Lokmanhekim, and Moy, 1964; Behls, Libovicz, and Engholm, April 1964, September 1964; Behls and Madson, 1965; Flanigan, Morrison, and Bass, 1966; Goldsmith, 1965; Libovicz, Madson, Behls, and Engholm, 1964; Libovicz, Van Schoyck, and Engholm, 1963; Madson, Baschiere, Behls, and Engholm, 1964; Madson, Behls, and Engholm, 1964; Madson, Libovicz, Behls, and Engholm, 1964). Most of these tests involved the use of simulated shelter occupants; these were mannequins which produced heat and humidity resembling that of a human being.

Studies were conducted on large, aboveground buildings suitable for fallout shelter by Guy B. Panero, Inc. (1965) in the New York City area and by Henniger and Madson (1966) and Poruk, Libovicz, and Engholm (1963) in the Chicago area. The investigators found that when cross-ventilation was available through open windows, natural air circulation was adequate to maintain habitable conditions most of the time in either summer or winter. In very large shelters, very little heat was lost by radiation or conduction to the walls of the shelter; the air ventilation provided the only mechanism for cooling (Combe, Nelson, and Tomcala, 1966).

Results of the other studies indicated that belowgrade shelters or shelters in the interiors of buildings without access to windows required forced ventilation at rates which depended upon the outdoor temperature and humidity; the higher the outdoor effective temperature (see Section 5.2.1 for a definition of effective temperature), the more ventilation was required. In warm weather, more than 3 cubic feet of air per minute must be supplied for each person sheltered, and in very hot weather, substantially more than 3 cubic feet per minute must be provided for each person.

Baschiere and Lokmanhekim (1964) calculated the summertime, forced ventilation requirements for different parts of the country. Their computations were based on meteorological data and the desire to limit the effective temperature inside the shelter to 82° (an effective temperature of 85°F had been shown to be the threshold of intolerance from previous shelter occupancy tests, see Section 5.2.1). The Defense Civil Preparedness Agency (May 1978), using modern meteorological data, has recalculated these ventilation rates for use in shelter design. Figure 5.1 is the result. It should be noted that very high ventilation rates are required in the hot, humid regions of the United States, such as along the Texas Gulf coast.



(Rates given in Cubic Feet per Minute required for each sheltered person)

Fig. 5.1. Forced ventilation requirements for U.S. shelter locations.

6. SHELTER NEEDS: SYSTEMS STUDIES

A most impressive collection of research literature has been devoted to the study of shelter systems; that is, how effective can they be, where should they be located, how much should they cost, and how do they interact with alternate civil defense postures? This section reviews the most important findings in these areas; however, there exists much more research than can be reported in detail here.

6.1 THEORETICAL STUDIES

In the 1960s and early 1970s, a variety of authors conducted mathematical systems analysis studies of nationwide blast shelter systems. In these studies it was usually assumed that the enemy was targeting population or Manufacturing Value Added (MVA) that was colocated with population. Some type of mathematical expression for shelter costs as a function of overpressure was usually assumed, and shelter was deployed with hardness assigned to areas depending on the population density. It was generally assumed the enemy had perfect information on the shelters and would retarget to offset, to the degree possible, the benefit gained by the deployment of shelter. Vortman (1962b) compared different deployment philosophies: uniform hardness, hardness proportional to population density, and maximum number of survivors for available budget for the Albuquerque, New Mexico, area. He found little difference in the approaches for 75% survival from weapons delivered within a 2-mile circle of equal probability (CEP).

Mitchell (1966) used a LaGrange multiplier technique to optimize deployment with hardness and cost varying with density. He calculated cost exchange ratios--the sum the adversary would have to expend in order to offset the investment in shelter.

Brown (June 1964b) developed a mathematical model for the cost of shelter for 213 urbanized areas in the United States. He found that with modest population movement to shelter, the requirement for very hard shelters is relieved, since the cost of shelter construction is much less in the surrounding rural areas. He found significant reductions in blast shelter costs by optimization and some overcrowding. Uher (1969) did a parametric study of optimum blast shelter systems against a variety of heavy attacks and limited civil defense budgets. He found that the optimum allocation of resources in terms of maximizing survivors was to leave the highest population densities undefended and apply the shelter resources in lower population density areas. To provide equal risk in the high-population-density areas would require extremely hard shelters which would be excessively expensive.

Haland (1970) did a systems analysis of a very hard blast shelter system designed to protect Detroit. He found total systems costs were lower when shelter hardnesses (overpressure resistances) were designed to be proportional to population density; although, this effect was small for low-budget programs. He found large uncertainties in shelter costs for shelters harder than 100 psi. For 100-psi shelter, he found costs per space ranging from $600 to $2000 in 1985 dollars. Considerable improvement in survivability and cost can be obtained by redistributing the population to reduce the highest peak densities. He found that isolated individual shelters are less expensive than interconnected shelters, due to the assumption that people will move out of the highest density areas in interconnected shelters, leaving some shelter unused.

The theoretical systems analysis studies of shelter systems done in the 1960s were useful and valid in a time when it was believed that multibillion-dollar civil defense programs were politically feasible. However, experience with urban mass transportation systems, such as those in Washington, Atlanta, and Miami, have shown that the assumptions of uniform known shelter costs, small number of designs, and ease of construction under existing cities were very optimistic.

6.2 SYSTEMS DESIGN STUDIES

A number of shelter system studies related to specific cities have been made. The systems include individual shelters and interconnected shelters in various combinations. Of interest is that their costs, when corrected to 1985 dollars are, with very few exceptions, fairly consistently in the range from $500 to $1000 per space.

The University of Arizona (June 1964) conducted a study of several shelter protection concepts for the Tucson, Arizona, area. These included four different designs of family shelters and three community shelter designs, including a network of corrugated metal culvert. The family shelter costs ranged from $24,000 to $48,000 in 1985 dollars and would hold up to eight people for a cost per person of $3000 to $6000 dollars. This high cost is due in no small part to the very elaborate entranceways designed for the shelter. A buried shelter with a yielding membrane roof is estimated at $256 per space (in 1985 dollars), which is questionably low. No prototypes of this type of shelter have ever been built. The same authors estimated $600 per space for a 100-psi reinforced concrete box shelter for 1000 people. A buried corrugated conduit network was estimated at $1068 per space (in 1985 dollars). The group making these cost estimates was an academic organization with unknown experience in actual construction.

Bechtel Corporation (1967) designed a conceptual system of 25-psi blast shelters for the city of Providence, Rhode Island. The shelters were largely belowgrade, rectangular concrete boxes with capacities from 1500 to 15,000 people. A few retrofit structures were also included. The average cost per space corrected to 1985 was $747. The shelters were sited in open areas around the city such as school lots, areas cleared for urban renewal, and institutional grounds. A design criterion was that the shelters had to be within 30 minutes walking distance of the entire population. This was an exceptionally well-done study by a credible and experienced engineering organization.

Ryan and Baum (1972) analyzed a nationwide program of slanted blast shelters made up of hardened basements installed in new construction. The system was designed to accommodate the 110 million residents living in the highest risk areas. They evaluated new basement construction throughout the country and estimated that enough new space would be constructed to shelter 95% of this population at 5 ft^2 per person or 80% of the population at 10 ft^2 per person. At 10 ft^2 per person they estimate the cost of the system at approximately $100 per space (in 1985 dollars). The system would reduce fatalities among the population at risk to less than 40% of their unsheltered vulnerability with an attack of 1500 weapons and to approximately 15% of the total population from an attack of 500 weapons.

The calculations of fatalities do not take into account initial nuclear radiation which is recognized by the authors as being a problem even for 1-MT weapons. Their dual-use design does not allow for the high doses at 70 and 90 psi from 1-MT weapons. They do not even consider the possibility of 100- to 300-kiloton weapons which are now much more of a problem. They also ignore the fire and rubble problem in highly built-up areas.

The Ryan and Baum study is very important in that it analyzes a cost-effective approach to providing blast shelter in high density population centers even though the costs are very optimistic. If this country ever builds a blast shelter system, this approach is almost certainly one of the ones that will be used for permanent shelter. However, slanting designs will have to be improved to deal economically with the very severe initial nuclear radiation hazard expected in future weapon deployments.

York, Wright, and Hill (1975) did a comprehensive review of the alternative ways of providing host area fallout protection for uses in conjunction with crisis relocation planning. They considered upgrading existing buildings, 15 designs of expedient shelters, and caves, mines, and tunnels. They assume that none of the 226 million identified fallout shelters (in 1975) would be located in the host areas. Generally, the most cost-effective shelter alternative is the use of existing caves, mines, or tunnels. The next most cost-effective alternative under the rules chosen is the upgrading of existing buildings. According to their method of evaluating shelters, expedient shelters are the least cost-effective but may have to be used if mines and caves or upgradable buildings are not available. This work attempted to select the most cost-effective mix of shelter options in circumstances when one or more of the required inputs was in short supply (e.g., excavating machinery or finished lumber).

This work also demonstrates a trap that systems analysts can fall into when they do not carefully examine their input assumptions. Their analysis indicated that the log-covered trench shelter (an expedient shelter) was not cost-effective, which is counterintuitive. On close examination, it was discovered that the authors arbitrarily restricted the log-covered trench shelter to four-person capacity because this was the size given in the example drawings in the reference they used (Cristy and Kearny, 1974). The materials and labor to construct the entryways, when divided over only 4 occupants, made the shelter less competitive with other designs. This shelter can be expanded with relatively little effort to accommodate as many as 24 people. However, this work is quite useful in laying out the alternatives and even provides a useful planning guide.

Barber and Sisson (1985) have developed a comprehensive review of means of providing shelter for essential workers with their planning guide. They provide three options: permanent shelter, prefabricated shelter to be put in place in a crisis, and expedient shelter to be built entirely in a crisis. They offer 10 shelter types which cover the three possibilities. They put emphasis on the expedient shelter, particularly the finished lumber version of the small pole shelter.

Their costs in 1985 dollars are generally under $1000 per space with most clustering between $600 and $850 dollars. Exceptions are upgraded mines at less than $100 per space and their expedient lumber shelter which they estimate at $300 per space.

The planning guide has a procedure for developing a site plan and for the crisis production of shelter. It is a very useful document.

The expedient finished lumber shelter and the corresponding standard finished lumber entrances to other shelters have a door design which makes them unsuitable for use in a blast environment which is likely to produce more than 1 to 2 inches of dust and rubble. The horizontal door is 5 or 6 ft down the vertical entry shaft and has very little clearance with the sides of the shaft. A few inches of dust, sand, or broken masonry blown into the shaft has a good chance of jamming the door shut and also pressing the blast valve closed. This defect can be remedied by moving the blast door to the surface and protecting it from the thermal pulse by whitewash or other means. This oversight on the part of a competent and experienced design group is cited as an argument for the need for continued field testing of new or modified shelter designs.

Sullivan, Heller, and Aldridge (1978) have produced the most recent and most authoritative analysis of shelter requirements in the literature. The study was sponsored by the Defense Civil Preparedness Agency with extensive participation of the civil defense community and other divisions of the Department of Defense. The study was done in 1977, and the report published in March 1978. The study presented six possible (candidate) U.S. civil defense programs with estimates of their effectiveness and costs: A - no program; B - the existing program; C - the best use of present shelter with no relocation; D - relocation of the risk area population; E - less extensive relocation with construction of expedient 15-psi blast protection; and F - extensive in-place permanent blast protection. These are summarized in Table 6.1.

Program D was selected by the Carter administration as the basis of its civil defense program. It provided the most improvement in survivability under the assumptions of the program (a crisis build-up permitting evacuation) for the money involved -- a $1.6 billion (in 1977 dollars) 5-year cost with a subsequent, annual cost of $200 million (in 1977 dollars). Under the assumptions of the scenario, Program D could be expected to save over 80% of the population.

Program F is a blast shelter program intended to produce 100-psi blast shelters in risk areas and fallout slanting in non-risk areas. It is an in-place program designed for surprise attack or attack with little warning and predicts a survival rate close to 90% of the population. The blast shelter component of the program was expected to produce 150 million shelter spaces at $350 per space (in 1977 dollars) for a shelter component cost of $53 billion dollars. The total blast shelter component would be $89.7 billion in 1985 dollars.

The blast shelter program would be complemented by fallout slanting in new construction in non-risk areas. This, it was estimated, would provide 100 million spaces at $25 per space (in 1977 dollars). This posture would make use of some crisis evacuation in the most expected circumstances, since the entire urban population could not be sheltered, at least initially. Presumably some expedient shelter construction and fallout upgrading would be required.

The shelter cost of $350 per space (equal to $587 in 1985) may be slightly optimistic. The report also considers a Program G which is a pair of possible additions to the other programs in

Table 6.1. Civil defense postures

	Number of people exposed and protection levels afforded under various proposed civil defense postures				
	Program B	Program C	Program D	Program E	Program F
	In-place present program	In-place fallout protection	Extensive relocation to farms/ hamlets[e]	Less extensive relocation[f] + 15-psi blast protection	In-place blast/fallout protection
Risk areas[a]					
Number of people[b]	140 M	140 M	- - 10 M keyworkers - - 20 M stay behinds		140 M
Protection levels[c]	4,2,10	100 M best available shelter[d] by psi >8,2,55 40 M at 5,2,40	keyworkers at 55,45,500 stay behinds: 15 M at >8,2,55 5 M at 5,2,40		100,100,500
Nonrisk areas					
Number of people[b]	75 M	75 M	185 M	185 M	75 M
Protection levels[c]	4,2,10	35 M best available shelter by PF >8,2,55 40 M at 5,2,25	35 M best available shelter by PF >8,2,55 150 M at 5,2,500	15,14,200	15,14,200

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[a] Risk areas include the 155 million people potentially exposed to blast overpressure of 2 psi or greater, given a massive mid-1980s Soviet counterforce/ countervalue attack.

[b] Assumed 10% spontaneous evacuation from risk areas in a crisis for "in-place" postures, and 80% of risk area population evacuated in "relocated" postures.

[c] The three numbers indicate: mean lethal overpressure (psi), mean casualty overpressure (psi), fallout protection factor (PF).

[d] According to National Fallout Shelter Survey inventory.

[e] Specifically, CONUS is divided into grid elements, 2 arc-minutes on a side. Grid elements are treated as follows: population >5000, 80% evacuated; population 2000-5000, no change; population <2000, host area for evacuees. Evacuees remain within a given state or group of small states over which the hosting ratio (final-to-initial population) is constant.

[f] Same as for Posture 3 (footnote e) except that: >10,000 evacuate 80%; population 5000-10,000, no change: population <5,000, host area for evacuees.

the study. Option 1 would add additional shelter in new construction by slanting 25-psi blast protection over the long term. It is estimated that spaces could be produced at $167 in 1985 dollars. If initiated in 1978, it was estimated that it could have produced 40 million spaces by 1985 and 150 million by the year 2000. This program would be accompanied by a shelter stocking program at $5.00 per space. The total program over nearly 20 years would be $20 billion (in 1977 dollars) with an annual cost of approximately $900 million (in 1977 dollars).

Option 2 envisioned a 1-year intensive civil defense buildup. It would consist principally of procurement of materials for expedient shelter for use in both risk and nonrisk areas costing approximately $18 billion (in 1977 dollars). The materials would be converted into shelters in a two-week crisis.

Sullivan, Heller and Aldrich (1979) in a subsequent publication made estimates of shelter space requirements for "high-risk areas" in the United States. Two categories of high-risk areas were identified. The first, with a population of 7 million, was the area around Minute-Man bases, Titan bases, Strategic Air Command bomber bases, and submarine bases. The second, with a population of 75 million, included the previous set of areas, but in addition, government research facilities as well.

While government research facilities hardly seem to be high value targets, the set of them could be a fair approximation of all the facilities engaged in the development, production, and storage of nuclear weapons which could conceivably be targets, in what is primarily a counterforce attack.

An option to protect the entire 140 million people in the urban-industrial target areas was also included. The authors evaluated three possible programs for these risk areas: first, crisis relocation; second, an expedient shelter construction program in a crisis; and third, the construction of dedicated blast shelters. The programs were costed using substantially the same costs as in their previous study. Blast shelters were estimated to cost $300 per space in 1979 dollars.

Expedient shelter kits were estimated to cost $70 per person in 1979 ($100 in 1985). Also estimated for each option were the associated costs of planning, warning, direction and control, radiological defense, emergency public information management, and research and development.

Table 6.2 is a summary of costs of the different program options in 1979 dollars. They can be converted to 1985 costs by multiplying by 1.44. It was estimated that all of the programs would result in about 80% survival of the affected population,

Table 6.2. Estimated costs to establish CD programs for high-risk areas (over 5-year period: 1979 $, millions)[a]

		Crisis Relocation			Expedient Shelters		Dedicated Blast Shelters		
	Current CD[b]	140M at Risk	75M at Risk	7M at Risk	75M at Risk	7M at Risk	140M at Risk	75M at Risk	7M at Risk
Shelter:									
Survey	10	60	60	60	60	60	c	c	c
Planning[d]	0	50	30	3	525	50	c	c	c
Material[d]	0	0	0	0	5,250	500	0	0	0
Peasetime construction	0	0	0	0	0	0	42,250	22,500	2,100
Marking	0	5	5	5	5	5	c	c	c
Stocking	0	260	140	13	110	10	700	375	35
Shelter management	0	50	25	5	25	5	100	55	10
Nuclear protection planning	46	200	130	55	130	5	500	290	70
Warning	32	50	50	50	1,100	100	2,000	1,100	100
Direction & control	39	325	205	80	205	80	335	200	80
Radiological defense	22	90	60	30	60	30	90	60	30
Emergency public info., training, education	5	150	80	10	80	10	150	80	10
Management	300	350	335	320	335	320	1,500	650	360
Research & Development	26	80	80	80	80	80	100	100	100
5-Year TOTAL COST	480	1,670	1,200	710	7,965	1,255	47,725	25,410	2,895
Annual Cost (1st 5 years)[a]	96	335	240	140	1,590	250	9,550	5,080	580
Annual Cost ($/U.S. citizen)	0.45	1.55	1.10	0.65	7.40	1.20	44.50	23.60	2.70

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[a] After program is established, annual maintenance costs are lower than these (except for Current CD).

[b] Based on FY 1979 DCPA appropriation, totalling $96.5 million for FY 1979.

[c] Included in peacetime construction.

[d] For development of shelters during crisis.

under the assumed design conditions of targeting and warning time. However, only the in-place shelter is effective under all attacks and warning times.

Additional information on civil defense postures and the trade--offs between various shelter deployment strategies is contained in the following references: Bechtel Corporation (1968); Brannon and Scala (1984); Brown (June 1964a, 1965a, 1967); Condit (1962a, 1962b, 1965); Cristy (1973, 1975); Devaney (1970); Fischer, Faby, Robinson, and Leonard (1984); Haaland (1969); Hamberg, Salee, and Watkins (1963); Harvey, E.C. (1964); Hendrey et al. (1981); IIT Research Institute (1964); Jones (1977); Logothetti et al. (1969); McMullan, Wright, Anderson, and Trustman (1967); Nehnevajsa (1976); Rockett (1969); Rockett and Brown (1967); Santini et al. (1982a, 1982b); Smith and Denton (1966); Staff of the Journal of Civil Defense (1967); Warner and Christiansen (1972); Waterman, G.S. (1959); Wright, Hill, Tolman, Lyday,and York (1975); York and McKnight (1978).

6.2.1 Shelter Incentive Programs

Perhaps the most difficult unsolved problem of civil defense is devising a politically and economically acceptable program to get the shelters built. In one of the best reports reviewed by this study, the very experienced team of Strope, Devaney, Laurino, and Wengrovitz (1985) did an in-depth review of this problem. The shelter system they selected was that proposed by H. L. Murphy (1975): a heavy concrete slab over the basement of new construction. They recommend a 30-psi standard hardness with a slab thickness selected to provide shielding against initial nuclear radiation at this overpressure from a 200-kT warhead.

They estimate costs per space of this basement construction ranging between \$230 and \$300, depending on the size of the shelter. For the 80 million people not in the risk area, they assume a slanted fallout protection factor of 100, costing \$50 per space. The national average for the whole program is in the neighborhood of \$230 per space. Overall program costs would be in the neighborhood of \$40 billion.

Eleven alternative incentive programs are presented. Five of the programs are mandatory and the remainder are voluntary. The only designed to make participation in the program a profitable venture is the preferred option. The eleven programs are listed in Table 6.3. They are rank-ordered first by estimated shelter yield and then by program costs for identical yields. The preferred program would be the mandatory construction of shelter in new Federal and State buildings for two years to gain experience and then an incentive payment program for four years.

This exceptionally well done study would be of great importance to any official considering the deployment of a shelter system in

Table 6.3. Comparison of alternative shelter incentive programs

Program		Annual yield (spaces)		Annual program cost		Cost per space	
No.	Title	All effects (millions)	Fallout (millions)	GNP (billions)	Budget (billions)	GNP ($)	Budget ($)
7.	Flat incentive payment[a]	$28.58	$11.10	$9.24	$9.22	$233	$232
5.	Mandatory plus nonprofit subsidy	11.52	2.55	3.00	1.33	213	95
8.	Grant plus loan subsidy[a]	11.52	2.55	3.03	3.01	215	214
9.	Loan and loan subsidy[a]	11.52	2.55	3.03	3.01	215	214
11.	Public sector grant plus tax credit[a]	11.52	2.55	3.15	3.13	224	223
4.	Mandatory with subsidy	9.17	1.76	2.58	1.30	236	119
2.	Mandatory shelter in all buildings	7.57	1.76	2.15	0.16	230	17
3.	Mandatory excluding small residences	6.53	1.42	1.85	0.16	233	20
10.	Public sector grant[a]	5.92	1.44	1.58	1.56	214	212
6.	Public housing qualification[a]	1.49	0.37	0.43	0.16	243	90
1.	Mandatory in Federal buildings	0.58	0.10	0.17	0.15	246	224

[a] Includes Program 1.

the United States. The costs estimated for the shelter may be slightly optimistic but may be achievable with very good management. There is only a brief mention of the possibility of underground building construction. There is no mention of modifying quarrying practices near cities to produce usable protected space.

6.2.2 Construction Resource Availability and Surge Shelter Programs

It is entirely possible that some event in the future would convince the U.S. population and authorities that we should have blast or fallout shelter for the population. It is quite likely that any event so traumatic as to produce that large a change in official policy would also provide incentive to acquire the shelter as quickly as possible. To this end, there have been a number of studies attempting to estimate how quickly we could provide permanent shelter under great urgency.

In an early study of the problem, Curione (1968) estimated construction resources availability in support of blast shelter programs. He concluded that the limiting factor would be trained personnel. He estimated that the economy could not absorb a program larger than $5 to $7 billion per year ($20 to $30 billion in 1985 dollars). This would permit the construction of fallout shelter (5 to 10 psi) in urban industrial areas over 5 to 10 years, or construction of up to 100-psi blast shelter in the most densely populated areas over a 10-year period. Curione's cost for 50- to 100-psi shelters was in the neighborhood of $1000 per space (in 1985 dollars). He considered shelters designed for overpressures as high as 1000 psi.

Kamath and Wright (1980) estimated the feasibility and costs of surge period shelter systems. They considered shelter programs protecting both critical workers and the general public in target areas. These authors considered six single-purpose shelter designs: 500-capacity reinforced concrete rectangular shelter; 1000-capacity reinforced concrete rectangular shelter; 500-capacity reinforced concrete arch shelter; 500-capacity steel arch shelter; 20-capacity corrugated steel culvert shelter; 12-capacity small pole shelter--lumber version. The authors evaluated various combinations of the shelters for up to 140 million risk area population, and a 3.2-million critical work force.

Their conclusions were: (1) the critical work force could be sheltered during a surge period as short as 3 months without significant impact on normal production and distribution patterns of resources; (2) steel is the most critical material and is needed in large enough quantities to disrupt normal usage patterns; (3) in order to provide in-place protection to the entire risk area population, a 6-month surge period and 50% of the nationally produced (in 1980) steel reinforcing bars and plate steel would be required; and (4) with a 12-month surge period the entire risk area population could be sheltered with 25% of the reinforcement and plate steel production. Their nationwide shelter program costs worked out to about $1.3 billion (in 1985 dollars) to shelter the critical work force and approximately $60 billion (in 1985) to shelter the 140 million risk area population.

For additional information on surge shelter programs and the availability of construction resources, the following references are suggested: Cristy (July 1973); Kamath and Wright (1981); Rockett and Brown (1965); Wright (1969).

6.2.3 Costs of Single-Purpose Shelter Systems

A large number of studies containing diverse types of dedicated, single-purpose blast shelter designs have been reviewed and summarized by Chester and Holladay (1983). They extracted the detailed construction costs of each shelter from each study and updated the costs into 1982 dollars. The revised costs for all shelter designs in a particular study were plotted as functions of both the designed overpressure (psi) and the designed occupancy (number of spaces) to ascertain the most economical shelter. Six such figures were developed by Chester and Holladay in their summary report, including four figures for shelter designs which included shock isolation equipment. In these figures, Chester and Holladay compared previous shelter costs to the cost of a proposed, corrugated steel culvert shelter; see Sect. 7.6.2.3.

In one of their figures, reproduced here as Fig. 6.1, the cost per space in 1982 dollars for the most economical shelters from each study is plotted as a function of designed overpressure protection from both static and dynamic loads. The dynamic load is given in atmospheres and is assumed to be one-half the designed resistance to the static load. Families of curves are used to present data for the various shelter sizes (number of spaces). To convert 1982 dollars into 1985 dollars use a multiplier of 1.09.

In Fig. 6.2, the cost per space for the most economical shelters from each study are plotted as a function of the designed number of spaces per shelter. Families of curves are used to present data for the various levels of overpressure protection offered by each design.

The basic shelter components included in the costs shown in these figures are:

1. earthwork (excavation and backfill);
2. basic structure construction (concrete work and metal work, including materials and labor);

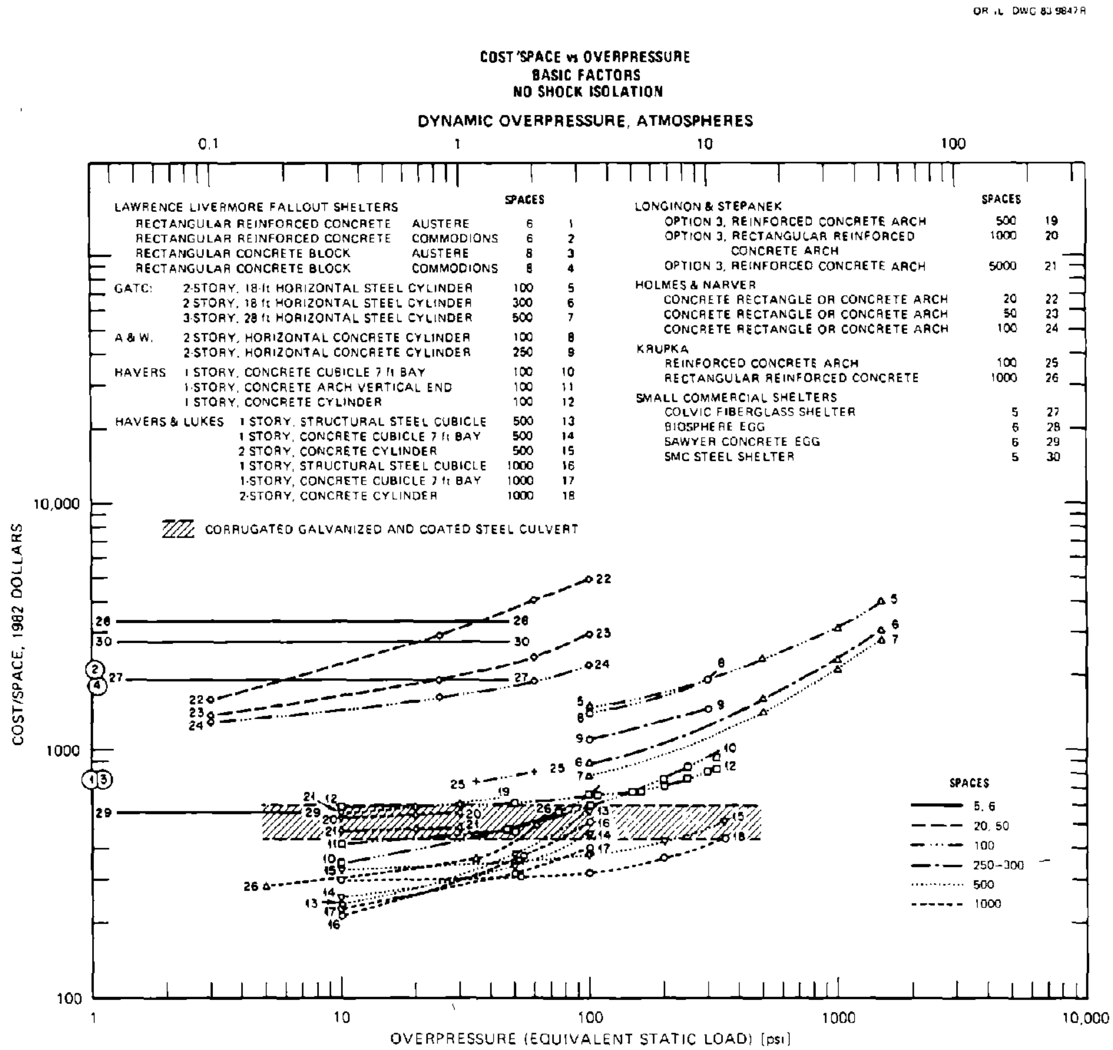

Fig. 6.1. A comparison of the most economical shelters from various design studies (cost vs overpressure protection).

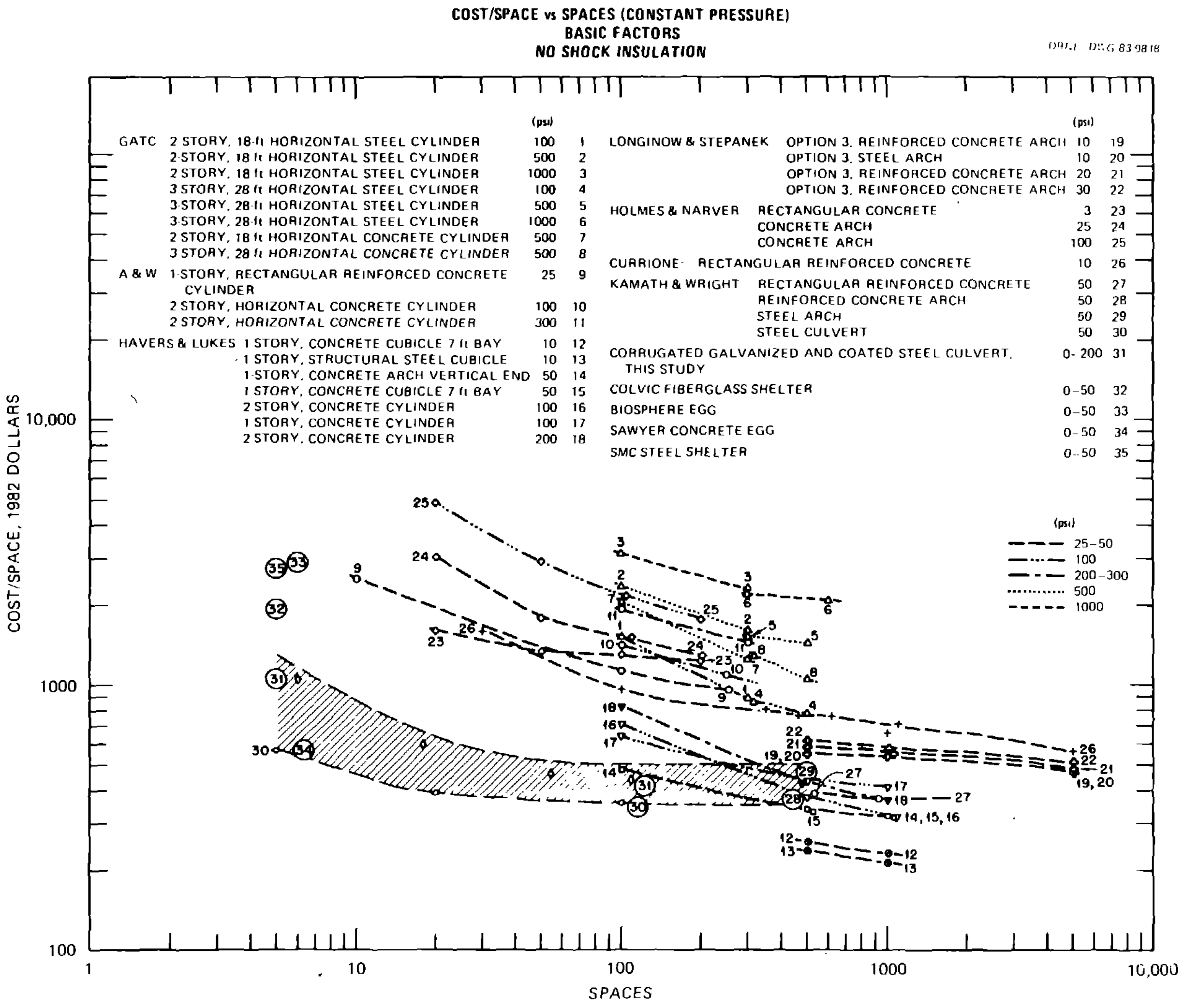

Fig. 6.2. A comparison of the most economical shelters from various design studies (cost vs shelter size).

3. entrances (materials and labor for excavation, blast protection, radiation shielding, stairways, etc.);
4. mechanical (primarily, ventilation equipment, including air blowers, duct work, external ventilation shafts, and necessary filters);
5. electrical (lighting, outlets, mechancial wiring, back-up genetator);
6. contractor's overhead, profit, and contingencies (taken as 20% of the prices computed in Figs. 6.1 and 6.2).

Key habitability items which were <u>not</u> included in the cost estimates were radiation monitoring and communications equipment, food, water, furniture, and sanitation equipment.

An initial inspection of Figs. 6.1 and 6.2 suggests several basic trends for blast shelter costs:

1. For a specific study, the cost per space decreases as the number of spaces increases. That is, larger shelters cost less on a cost per space basis.
2. For a specific study, the cost per space increases as the level of overpressure protection increases.
3. For a specific study, the cost per space varies according to the type of architectural design (arch, cube, cylinder, steel construction, concrete construction, etc.).
4. The corrugated metal culvert shelter and the shelters of Havers and Lukes (1964) are among the most economical shelter designs, regardless of shelter size or overpressure protection level.

Additional information on the cost and effectiveness of civil defense shelter systems is contained in the following references: Ammann and Whitney (1960, 1963); Avise et al. (1971); Barksdale and Wade (1967); Bobrow (1965); Bothun (1957); Childers, Vansant, and Mokrauer (October 1968); Curione (1958, 1967): Defense Civil Preparedness Agency (November1972a); Devaney (1964); Flynn (1962); Forrestal (1963); Gant and Haaland(1979); Goen, Radden, and Goodrich (1968); Goen, Ryan, Kamradt, Baum, and Radiovic (1966); Granzow, Summers, and Bliss (1964, January 1965, June 1965); Haaland and Chester (1981); Harvey, T.F. (1982); Havers (1963); Havers and Lukes (1964); Holmes and Narver (1960); Kearny (1963); Kelleher (1965); Krupka (1963, 1964a); Krupka et al. (1963); Lawrence Radiation Laboratory (1961); Longinow and Stepanek (1968); Longinow, Kalinowski, Kot, and Salzberg (1970, 1971b); Ralph M. Parson, Company (1968); Rockett (1966); Rockett and Brown (1967); Schmidt (1971); Strope and Devaney (1978, 1979); Vortman (1962a); Waterman, G.S.(1959); Weinstein (1983); Welch (1964).

6.3 ACTIVE-PASSIVE DEFENSE INTERACTION

In the mid to late sixties active consideration was given to the deployment of a ballistic missile defense. The system under consideration would have utilized a combination of a long-range exoatmospheric interceptor (the Spartan) and a short-range endoatmospheric interceptor (the Sprint). Both interceptors were armed with nuclear warheads. Deployments were considered until they were restricted by the ABM treaty of 1972. During this period a number of studies were conducted to investigate the interaction between active defense designed to protect cities and blast shelters for the population in cities.

William Brown (July 1964, 1965) at the Hudson Institute was a pioneer in active-passive interaction. In the course of considering the interaction with active defense, he proposed making shelter hardness proportional to population density, permitting some population dispersal in a few hours before an attack, and overcrowding blast shelters, as ways of dramatically increasing the effectiveness and decreasing the cost of the passive component of the active-passive mix. He developed mathematical relationships between overpressure and survival, the spatial distribution of shelter population density, and shelter cost versus overpressure hardness. He considered up to five different shelter types in the mix. He found that low expenditure levels (a few billion dollars) favored allocating the entire expenditure on shelter. As shelters became more cost-effective, the optimum solution favored more expenditure on active defense. For many cases a 50-50 split in the budget between active and passive systems was relatively insensitive to the effectiveness of the active system or the size of the attack. Brown was one of the few people who also considered the effects of active systems in increasing the survival of industrial assets.

Grimm, Pearsall, and Pratt (1971a, 1971b, 1971c, 1971d) conducted a mathematically elegant study using LaGrange multipliers to calculate the allocation of a fixed budget between an active defense using Spartan and Sprint missiles, and a shelter system using single-purpose shelter. The study included mixes of the two active possibilities and one passive with up to six types of offensive warheads. It took into account a finite time for people to move to shelter and assumed that the object of the attacker was to kill as many people as possible. The study did not consider other methods of delivering weapons such as fractional orbital bombardment systems, submarine launched ballistic missiles, and air launched cruise missiles. Evacuation of the population was not considered. The study found that the different types of defensive systems were weakly complimentary rather than competitive (i.e., expenditures on a mix of the systems were generally more effective than the same expenditure on any one system).

Haaland, Wigner, and Wilson (1971) conducted an elaborate and mathematically sophisticated study on the active defense expenditure to reduce the casualties from a surprise attack from submarine launched ballistic missiles. Once again, the assumption was that the attacker's objective was to kill as many people as possible. The Safeguard Ballistic Missile Defense technology was assumed, employing Spartan and Sprint interceptors and expensive radars. There were three shelter postures, including slanted new construction to provide blast protection as a way of reducing cost. The study found that combinations of active and passive defense were more effective in this very limited scenario than either one alone.

In 1986, consideration is once again being given to the development and deployment of an active ballistic missile defense. It may be that the inevitable studies of the interaction between active and passive defense may make use of the additional understanding of shelter that has been obtained in the last 25 years. It is likely that any seriously considered deployment in conjunction with active defense would contemplate a finite number of shelter types rather than a continuously varying hardness in shelter design. The real effective hardness (mean lethal overpressure or MLOP) for any given shelter type would vary with the conditions at the shelter site--rubble potential from surrounding high-rise buildings, the water table, and the presence of open areas permitting buried construction--all of which would be beyond the control of the shelter designers. In view of the experimental work of Kiger and his co-workers (Kiger, Eagles, and Baylot, 1984; Kiger, Slawson, and Hyde, 1984), mean lethal overpressures of shelters would be determined by initial nuclear radiation for nonburied basement shelters, by ground motion, especially in alluvial soils, and by rubble in central business districts.

Evacuation would almost certainly occur in a very wide range of crisis scenarios. This would reduce peak daytime populations in central business districts.

Shelter design hardness greater than 50-100 psi would probably not be contemplated, although buried shelters in this range usually have very much higher effective hardnesses. For buried structures cost depends very little on designed overpressure protection levels less than 100 psi. As has been noted elsewhere, anything put in the ground has an inherent blast hardness approaching 200 psi.

The Soviet Union claims to target industry, government, and communications as countervalue targets, not people per se. If that were to be the case, a countervalue attack would consist largely of airbursts optimized for something in the order of 20 psi. Fifty-psi shelters would survive this type of attack right into the ground zeros beneath the weapons. Except for the possible effects of initial nuclear radiation, rubble, and fire, there would be no fatalities in shelters.

Since any active defense system is going to leak, shelters should logically be the bottom layer on a multilayered active defense. Fifty-psi shelters would reduce the casualties produced by warheads, which penetrate the layers of active defense, to levels far below that which would be inflicted on an unprotected population. The potential for a ballistic missile defense that could reduce the number of arriving warheads to the point where damage patterns from the individual weapons would no longer overlap makes even 10-psi shelters useful.

Perhaps the biggest interaction between ballistic missile defense and shelter is the potential change in political climate in the country. Such a change might be effected by recognition that an effective defense is technically possible. If this in turn were translated into the political will to spend hundreds of billions of dollars for active defense, it could make feasible the expenditure of tens of billions of dollars for an effective shelter program for the population.

For additional information on the role of shelters in active-passive defense, the following references are suggested: Haaland (1971); Haaland and Chester (1981); Haaland and Heath (1972); Latter and Martinelli (1968); Uher and Noojin (1967); Weinstein (1983).

7. SHELTER OPTIONS

7.1 BEST AVAILABLE SHELTER

If in a nuclear crisis, there is warning of an impending attack of only a few minutes to a few hours, there would be no time to evacuate. Given the present civil defense capability of the United States, the only measure available to the public would be to take shelter in buildings designated as part of the National Fallout Shelter Survey (NFSS) inventory and in home basements. In risk areas the NFSS inventory consists of many large masonry buildings which may offer significant protection in their basements. Figure 7.1 demonstrates where and how much fallout protection is found in different building types.

Table 7.1 is a tabulation of data from the NFSS inventory as of June 30, 1985. According to this information, there are more than enough spaces for the population of the United States in shelters with protection factors of 40 or more; however, the location of these shelters does not always match the distributed population. Table 7.2 is an estimated breakdown of these spaces based on a statistical sample by construction type (Longinow, 1979). The statistical breakdown of the spaces was done by Tolman, Lyday and Hill (1973). Unfortunately most of these spaces are in the aboveground portions of the building. Only 35.6%, a total of 63.7 million spaces, are in basements.

Basement spaces also offer some protection against blast. This protection has been extensively analyzed over the years by Longinow (1979). Figure 7.2 shows the indicated survival probabilities as a function of blast overpressure for different types of concrete basement construction in large buildings. There is general agreement that the principal mechanism of casualty production is collapse of the basement ceiling under blast loading. High pressure air jetting into unprotected basement entrances can produce significant casualties among people who are standing, but relatively few among those who are lying down and out of the direct line of the entryway (Longinow, 1979, 1980; Longinow, Hahn, Wiedermann and Citko, 1974; Longinow, Wiedermann,Citko, and Iwankiw, 1976). At the low blast pressure at which the non-upgraded basements will collapse, initial nuclear radiation is not a significant problem.

There are some exceptions to the effectiveness of the basement shelter as an in-place shelter option. In highly built-up central business districts, where buildings of four or more stories may be constructed side by side, blast waves of only a few psi will produce rubble many feet deep. It has been estimated by Longinow, Waterman, and Takata (1982) that fire in

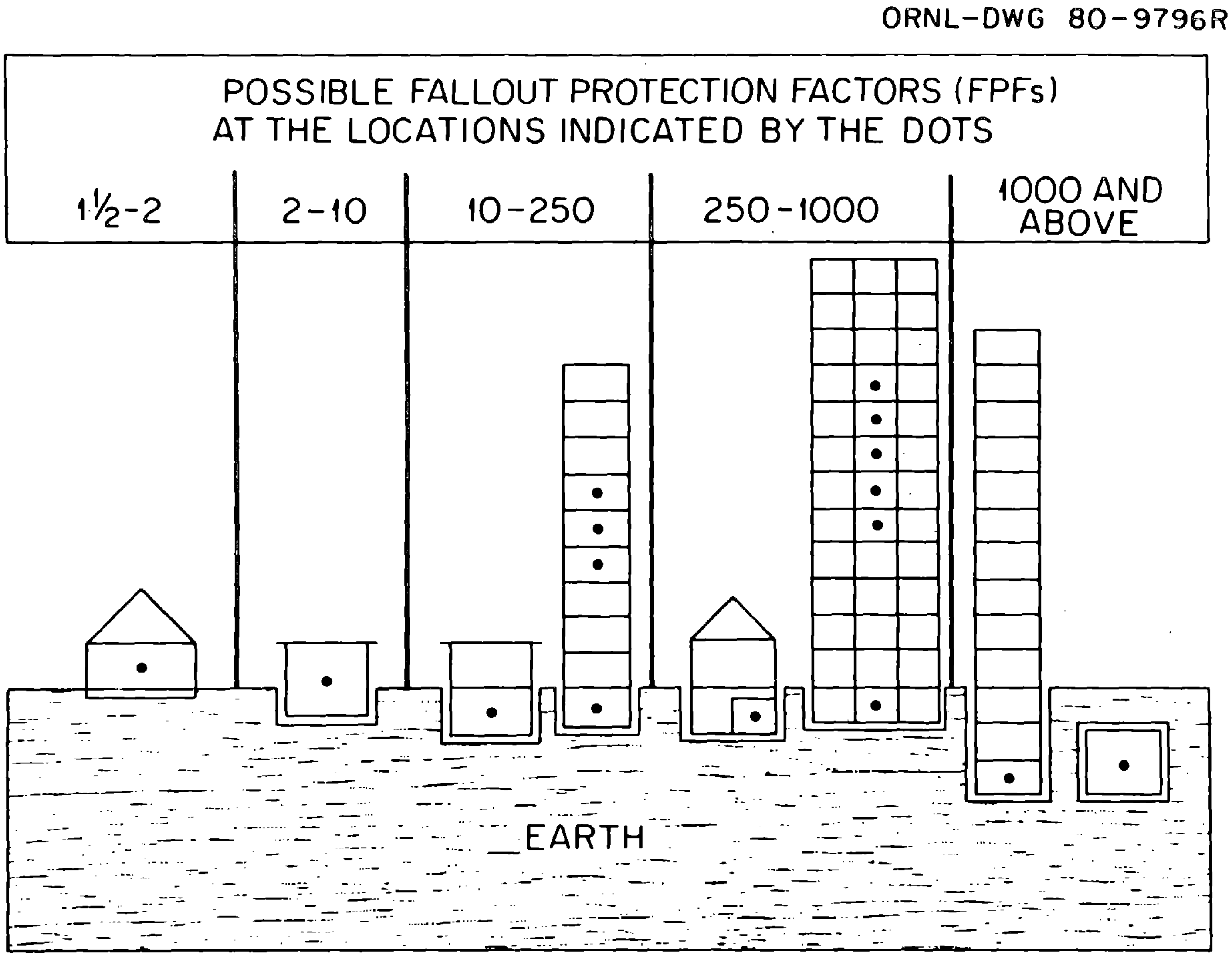

Fig. 7.1. Fallout protection available in various structures.

Table 7.1. Fallout protection factor distribution of U.S. National Fallout Shelter Space (NFSS) inventory (as of June 30, 1985)[a]

Class	Protection factor	Number of spaces
0	10-19	81,108,351
1	20-30	69,338,266
2+3	40-99	136,514,694
4	> 100	109,274,300
2+3+4	> 40	245,788,994

[a] Personal communication, Ms. Marion Rothenbuhler, Shelter Data Branch, Federal Emergency Management Agency, Olney, MD, November 25, 1985.

Table 7.2. Basement overhead (1st) floor system categories

Type of floor system	Percent of total U.S. spaces,[a] %	Mean lethal overpressure,[b] psi
Concrete slab - steel beam	22.1	12
Flat slab	4.9	8
Flat plate	5.7	7
Concrete slab - concrete beam	16.9	
Concrete joist - concrete beam	0.8	7
Concrete joist - steel beam	2.1	10
Other - Concrete slab - concrete joist Concrete slab - steel joist Concrete slab - steel/concrete beam Hollor concrete slab	20.3	7.5
Total Sample	72.8	

[a] Estimate based on 219 buildings sampled (Tolman, Lyday, and Hill, 1973). These numbers must be multiplied by 35.6% to get percentages of this type of construction located in basements. Of all spaces, 9.4% are located in basements and subbasements with no exterior wall exposed. (Longinow, 1979)

[b] Defined as that blast overpressure which will statistically produce fatalities in 50% of those exposed to the blast wave.

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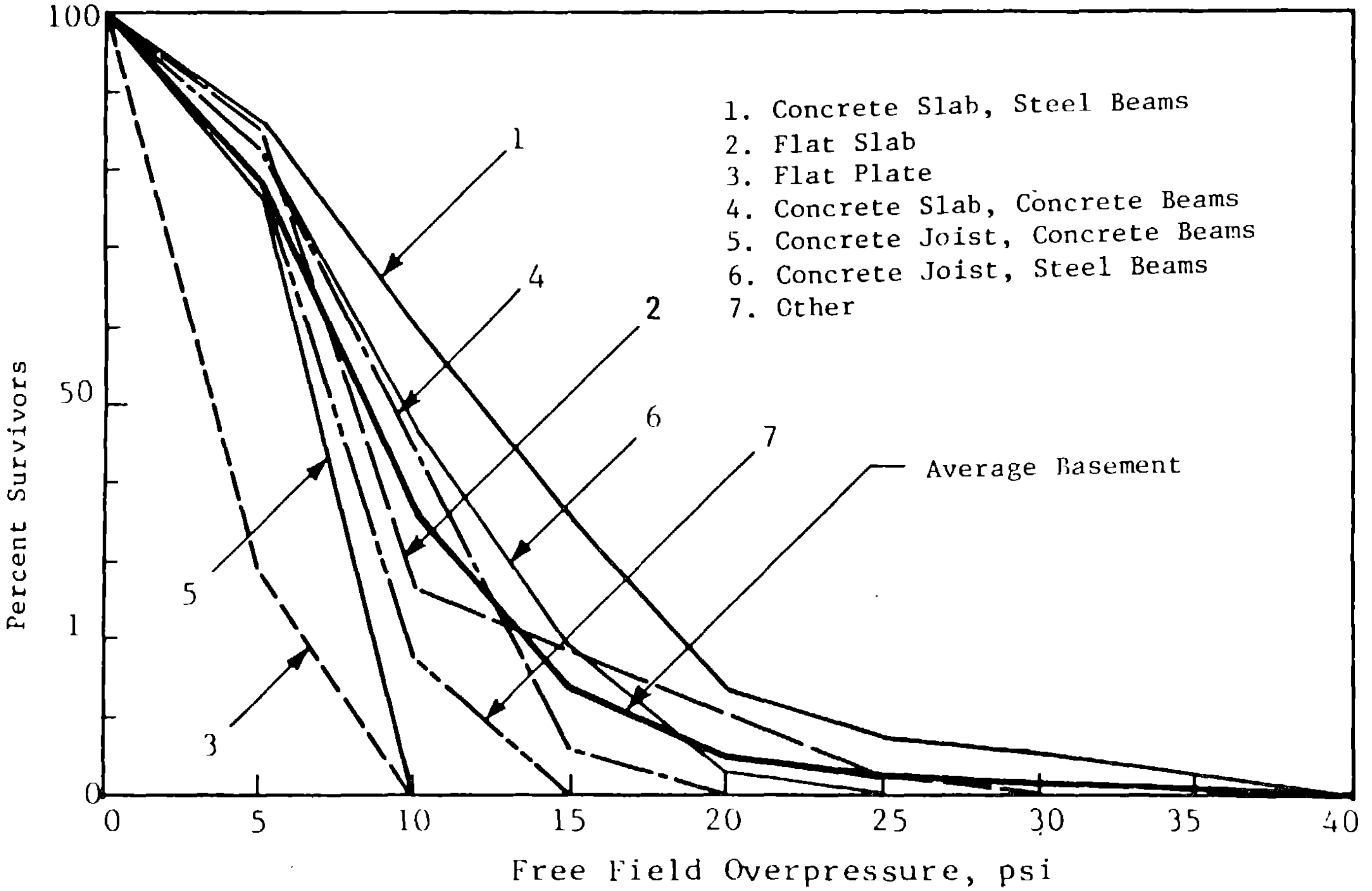


Fig. 7.2. Survival probability in basements.

this debris might occur and could endanger survivors in basement shelters covered by it.

The other problem with low overpressure shelters in risk areas is that of overlapping blast patterns from multiple weapons. An unsheltered person has only about 50% chance of survival at the 4-psi overpressure level. In an area attacked by a single weapon, there is a significant improvement in the likelihood of survival for a person inside a 10-psi shelter. His mean-lethal overpressure goes from about 4 psi to 10 psi, reducing the lethal radius of the weapon by a factor of 2 and the lethal area of the weapon by a factor of 4. There is an equal reduction in the probability of not surviving. However, if a pattern of weapons is laid down on an area, it will be designed to subject substantially the entire area with some overpressure, typically 10 to 20 psi, selected by the designer of the attack to produce the desired effect. There is then very little of the target area that is subjected to overpressures between 4 and 10 psi, where these best available shelters can improve survivability.

Single-weapon attacks are conceivable from terrorists, Third World countries with mentally unstable leaders, or accidental or unauthorized launches from the other nuclear powers. Against this type of contingency, a factor of 4 reduction in casualties is well worth attaining. The existing system of best available shelter would provide very few additional survivors in the event of an all-out attack on population centers.

For additional information on existing or best available shelter, the following references are suggested: International Council of Educational Facility Planners (1973); Goodrich (1965); Hill et al., (1967); Hill and Parker (1965); Longinow (1974); Office of Civil Defense (1960, 1964); Spangler and Jones (1984); Summers and Burson (1966); Wiehle (June 1974,December 1974); Wiehle and Bockholt (1968, 1970, July 1971, October 1971); Wiehle and Durbin (1966); Wilton, Zsutty, and Willoughby (1983).

7.2 CRISIS UPGRADING

A potentially important source of shelter in a crisis could be existing buildings upgraded by the addition of earth shielding to floors or to roofs and piled against the exterior walls. Floors can be strengthened by the addition of material to the bottom edge of the joist or by breaking the span of joists with improvised support columns. In this way, basements can be enormously strengthened by additional supports for the first floor and coverings for openings. The blast resistance of frame buildings can be increased to a few psi in many cases, and buildings with heavy concrete first floors with long unsupported spans can have the overpressure protection of the basement raised to tens of psi.

Murphy, Wiehle, and Pickering (1976) did some of the early work on upgrading basements for radiation and blast effects. They concentrated on Emergency Operating Centers, developing expedient techniques for support joists and developing high strength closures (Murphy, 1977; Murphy, et al., 1976). Work was extended to building basements as shelters for critical workers. It was found that overpressure hardness could be increased to 30 to 50 psi if the unsupported spans in the basement were 18 ft or longer and if there were no exposed exterior basement walls. Even with these circumstances they found that upgrading existing structures is less cost-effective than constructing various designs of corrugated metal or expedient buried shelter (Murphy, 1980a, 1980b).

Longinow (February 1978, August 1978) found that people could survive a few psi of blast in structures without upgrading modification. Upgrading the structure significantly increases the blast hardness. Longinow and Joyce (1980) found that wood floors in an old residence were 4-1/2 times stronger than their design load. Breaking the span with a stud wall could quadruple this strength. The caveat is that the strength of first floors in frame dwellings differ widely.

Gabrielsen, Cuzner, and Lindskog (1979) found that great improvement in the strength of existing basements could be obtained by simple shoring. A wood structure shored at the one-third points along the span of the joists gave a tenfold increase in ultimate strength. A reinforced concrete slab with single shoring gave a threefold improvement. This work indicated the possibility of obtaining a 30- to 40-psi shelter from a standard concrete floor system.

Wilton, Gabrielsen, and Tansley (1980) prepared a manual for upgrading shelters in the host area. The described upgrading techniques were principally to support the weight of additional earth for fallout shielding. Tansley and Bernard (1981) developed a similar manual for keyworker shelters. This manual covers both upgrading existing space and expedient shelter. The manuals were based on information developed in Gabrielsen, Tansley, and Cuzner (1980, 1981); this information was tested at the MILL RACE high-explosive test (see Section 5.1.2).

Tests of first-floor shoring systems and basement walls were reported by Tansley, Bernard, Cuzner and Wilton (1983). No failures of walls were observed.

Black (1975) also demonstrated methods of strengthening floors by reinforcing floor joists. Huff (1978) demonstrated the upgrading of an existing slab-on-grade structure by piling dirt on the roof and against the wall to provide fallout protection. In addition, a covered trench shelter was excavated underneath the floor slab.

Crisis upgrading is a very feasible method producing much shelter space in host areas in a crisis. It has the advantage of requiring no investment prior to the crisis other than the development of information and the distribution of printed material. This might be minimized by the production of camera--ready copy for reproduction in a crisis. The method suffers from the profound disadvantage of requiring some time for evacuating people from risk areas and more time to upgrade the shelter in host areas.

The research in this area supports the intuitive suspicion that constructing separate expedient shelters underground is more cost-effective than trying to upgrade even concrete basements to a hardness above 10 psi, particularly if the basements have large openings.

For additional information on crisis upgrading of existing structures or shelters, the following references are suggested: Ammann and Whitney (January 1965); Longinow, Wu, and Mohammadi; (1982); Smith, Cousins, Miller, and Newman (1964); Summers and Burson (1966); Tansley (1985); Tansley, Cuzner, and Wilton (1982); Tansley, Gabrielsen, and Cuzner (1981); Wilton, Gabrielsen, and Tansley (1981); Zaccor, Wilton, and Bernard (1981).

7.3 EXPEDIENT SHELTER

Expedient shelter is defined as shelter constructed, usually in one or two days, from common materials with tools and labor at hand. Most designs are planned in such a way that they can be quickly constructed by families that have made no preparations for shelter prior to the crisis. Most expedient shelter is designed for protection against fallout, although many models provide protection against low levels of blast (a few psi). One version has demonstrated hardness in excess of 100 psi.

7.3.1 Expedient Shelter Designs

The simplest expedient shelter is a foxhole. Dug 30 in. wide and 4 ft deep, it provides the occupant with a fallout protection factor of about 40. If covered with a canopy (a shower curtain or bed sheet) which is kept free of fallout, the occupant sitting in the foxhole could have a protection factor of about 200.

Many expedient shelter designs exist. Concepts for covered trenches made with doors or planks were published in the early 1960s by workers from the Stanford Research Institute (1961). Extensive development, testing, and documentation of this form of shelter were carried out by workers at the Oak Ridge National Laboratory in the 1970s (Cristy, July 1973; Cristy and Kearny, 1974; Kearny, 1976, 1979).

Expedient shelter designs on the following pages will illustrate the concept. Figure 7.3 illustrates some different techniques of constructing a shored trench shelter. This type of construction has withstood blast pressures of 20 psi and provides a fallout protection factor, with due attention to entrances, of about 200. Figures 7.4a and 7.4b demonstrate a simple pole--covered trench which can be constructed with unshored walls if the soil is sufficiently firm.

An even simpler shelter to construct is the door-covered trench illustrated in Fig. 7.5. This version is constructed using interior doors which are available in most American homes in quantities sufficient to shelter the occupants.

In areas where the water table or rock is too close to the surface to permit digging a trench, there are varieties of shelter which can be fabricated from combinations of poles, doors, and bed sheets. Figure 7.6 illustrates a shelter constructed from earth rolls (improvised sandbags) with the earth contained by bed sheets and covered with interior doors. Figure 7.7 is a variant using wood poles in areas where they are available. Figure 7.8 illustrates a ridge-pole shelter. It has some blast resistance but requires a large amount of wood for its construction. A great deal of labor is required to move the earth to cover it.

In regions expecting high blast pressures it is possible to build shelters capable of withstanding overpressures in excess of 100 psi. Figures 7.9a and 7.9b show the construction details of the small-pole shelter. This shelter, adapted from a Soviet design has demonstrated great blast hardness (Kearny and Chester, 1974, 1978; Kearny, Chester, and York, 1980).

7.3.2 Construction and Occupancy Experiments

In experiments carried out in many areas of the United States, it has been repeatedly demonstrated that average untrained citizens can construct shelters from these illustrated, step-by-step instructions in 24 to 48 hours when offered a cash incentive (Kearny, 1976; Condie et al., 1978.) These experiments give a strong indication that Americans would be willing and able to expend the labor to construct these shelters if they were convinced that the possibility of a nuclear attack were real.

The expedient shelter option has a number of attractive aspects. Perhaps the most attractive is that it requires little investment before a crisis. The cost to the government of such a program would be that of simply preparing and maintaining camera--

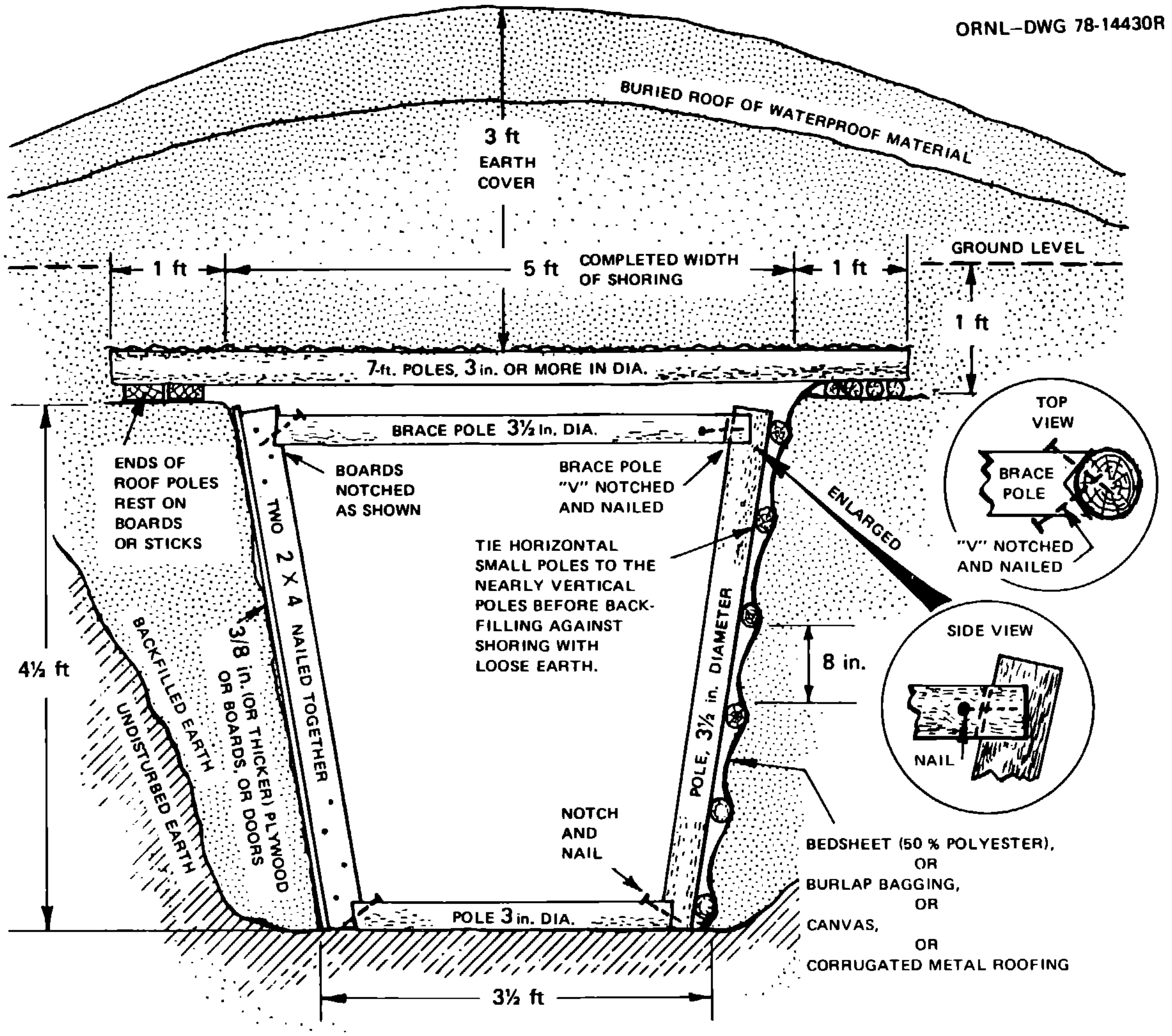
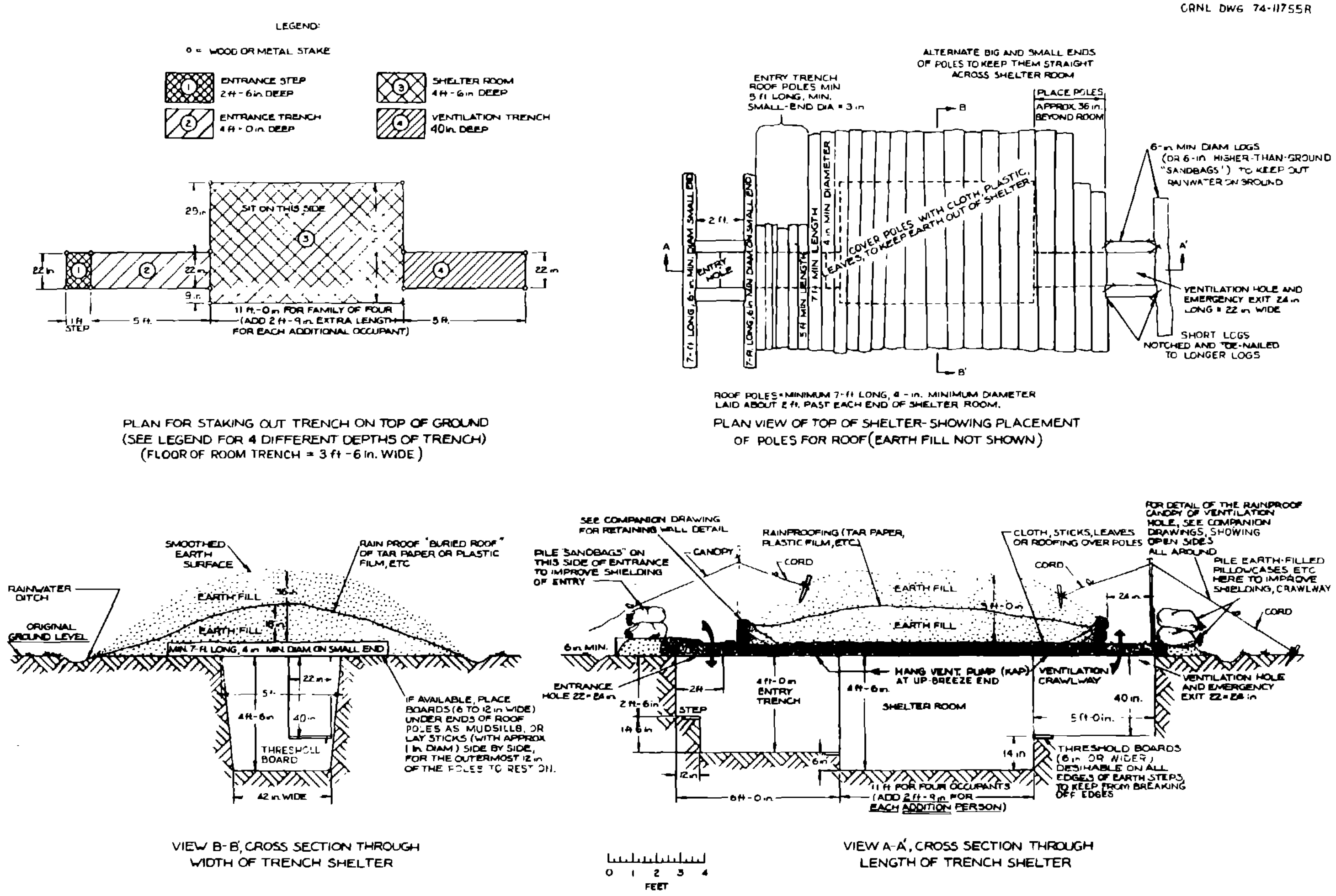


Fig. 7.3. Methods for shoring a trench shelter.



PLAN FOR STAKING OUT TRENCH ON TOP OF GROUND
(SEE LEGEND FOR 4 DIFFERENT DEPTHS OF TRENCH)
(FLOOR OF ROOM TRENCH = 3 ft - 6 in. WIDE)

PLAN VIEW OF TOP OF SHELTER-SHOWING PLACEMENT OF POLES FOR ROOF (EARTH FILL NOT SHOWN)

VIEW B-B', CROSS SECTION THROUGH WIDTH OF TRENCH SHELTER

VIEW A-A', CROSS SECTION THROUGH LENGTH OF TRENCH SHELTER

Fig. 7.4a. Pole-covered trench shelter.

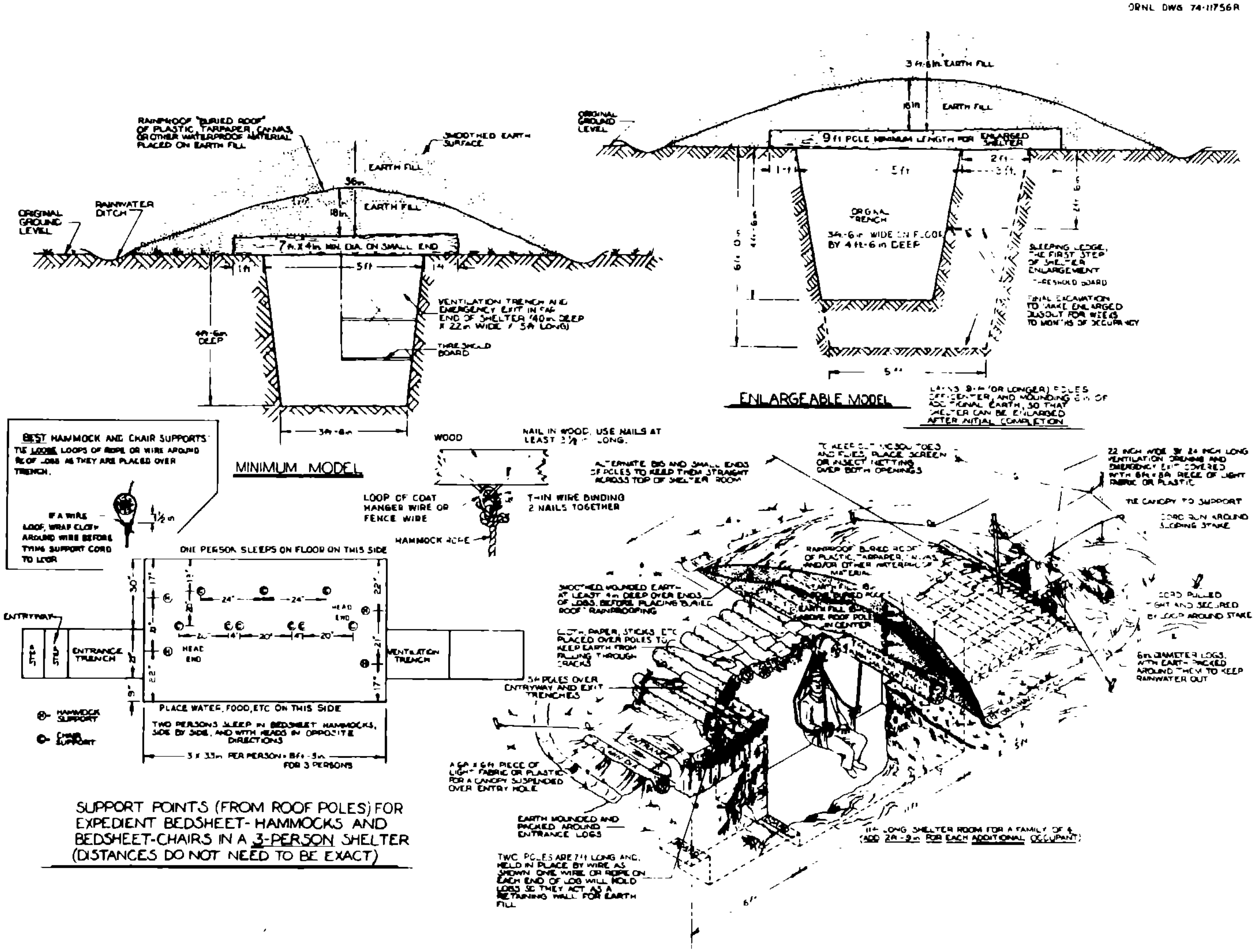
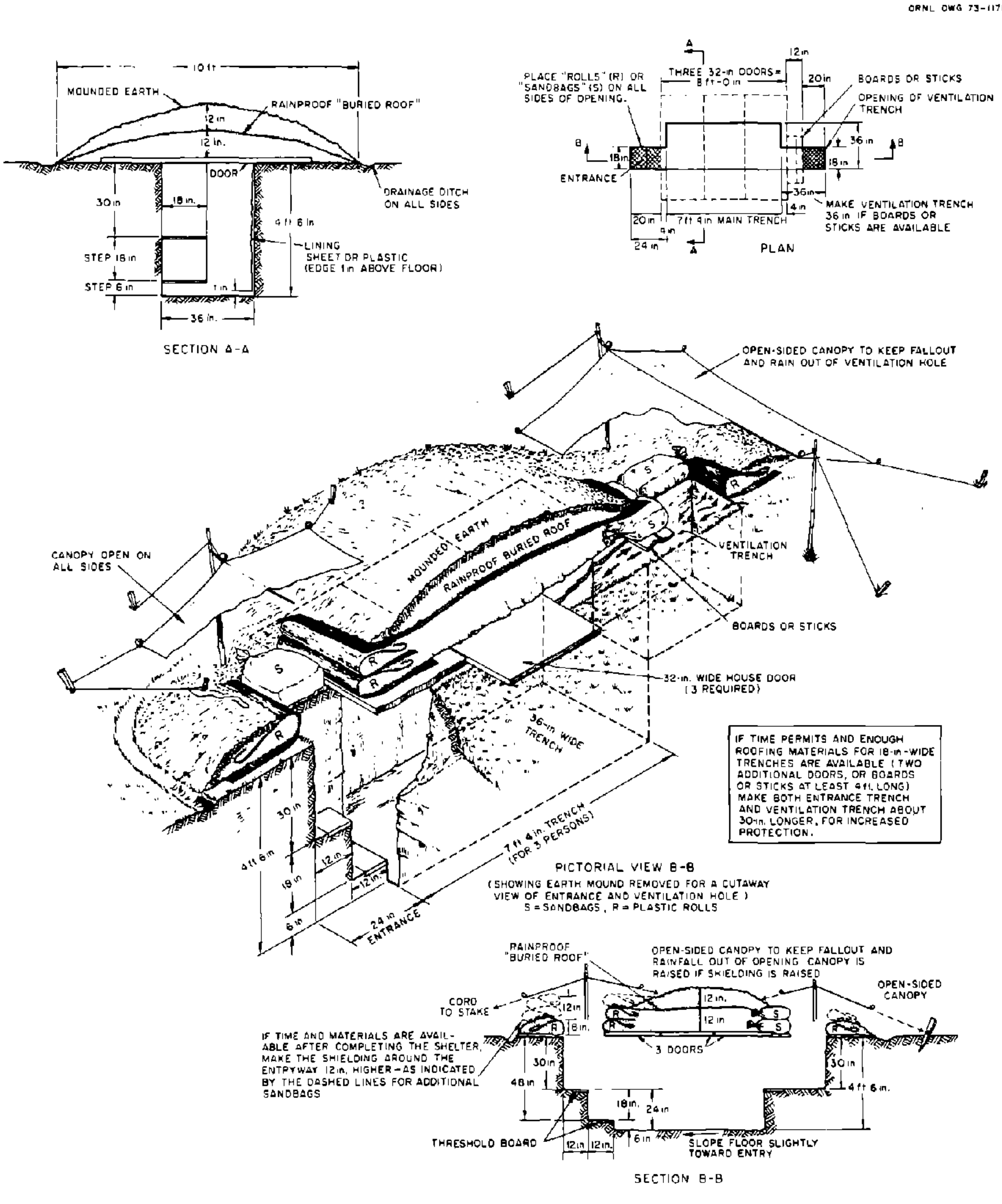


Fig. 7.4b. Pole-covered trench shelter.



IF TIME PERMITS AND ENOUGH ROOFING MATERIALS FOR 18-in-WIDE TRENCHES ARE AVAILABLE (TWO ADDITIONAL DOORS, OR BOARDS OR STICKS AT LEAST 4 ft. LONG) MAKE BOTH ENTRANCE TRENCH AND VENTILATION TRENCH ABOUT 30-in. LONGER, FOR INCREASED PROTECTION.

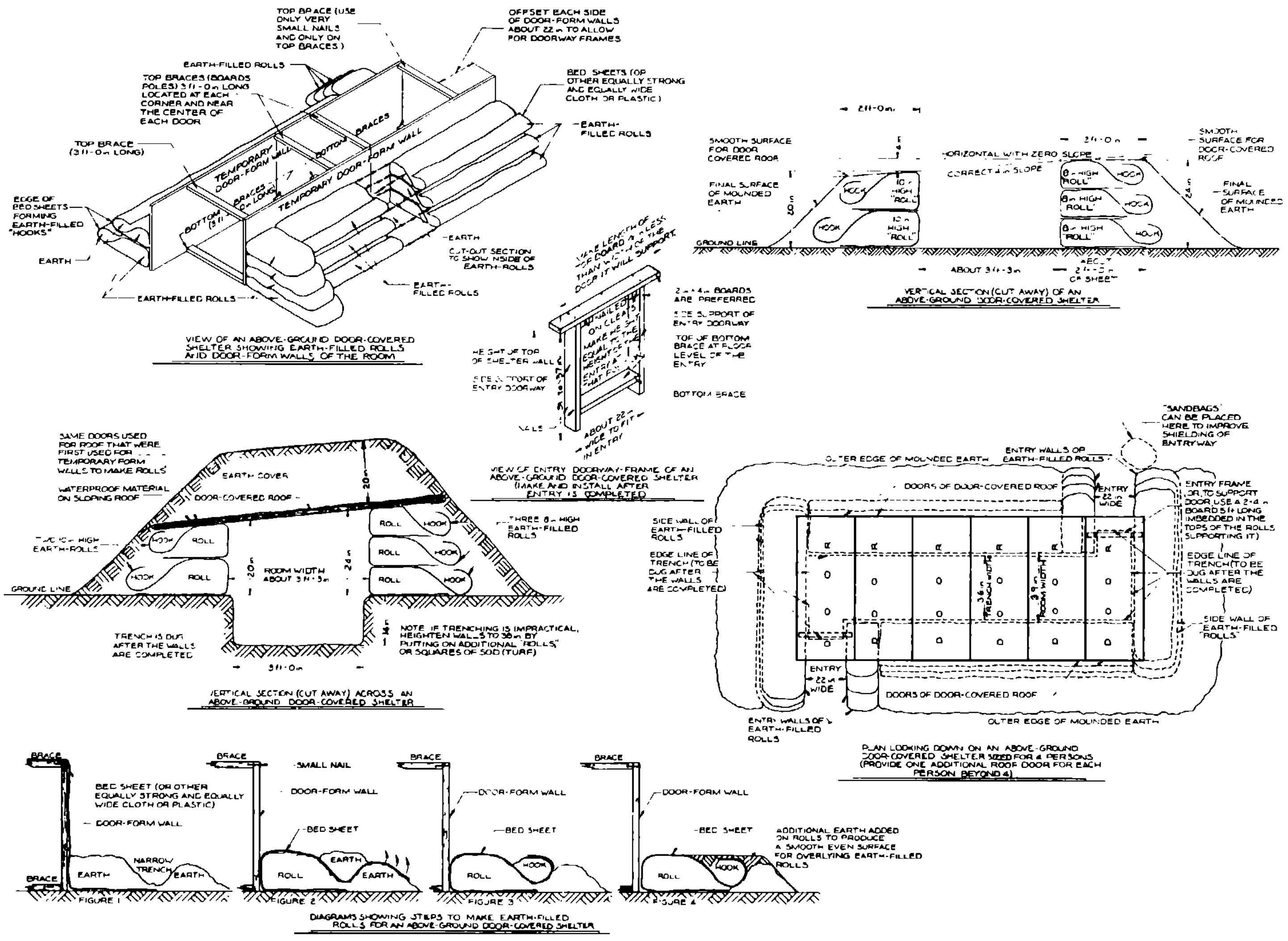
PICTORIAL VIEW B-B

(SHOWING EARTH MOUND REMOVED FOR A CUTAWAY VIEW OF ENTRANCE AND VENTILATION HOLE)
S = SANDBAGS, R = PLASTIC ROLLS

IF TIME AND MATERIALS ARE AVAILABLE AFTER COMPLETING THE SHELTER, MAKE THE SHIELDING AROUND THE ENTRYWAY 12 in. HIGHER—AS INDICATED BY THE DASHED LINES FOR ADDITIONAL SANDBAGS

SECTION B-B

Fig. 7.5. Door-covered trench shelter.


VIEW OF AN ABOVE-GROUND DOOR-COVERED SHELTER SHOWING EARTH-FILLED ROLLS AND DOOR-FORM WALLS OF THE ROOM

VIEW OF ENTRY DOORWAY-FRAME OF AN ABOVE-GROUND DOOR-COVERED SHELTER (MAKE AND INSTALL AFTER ENTRY IS COMPLETED)

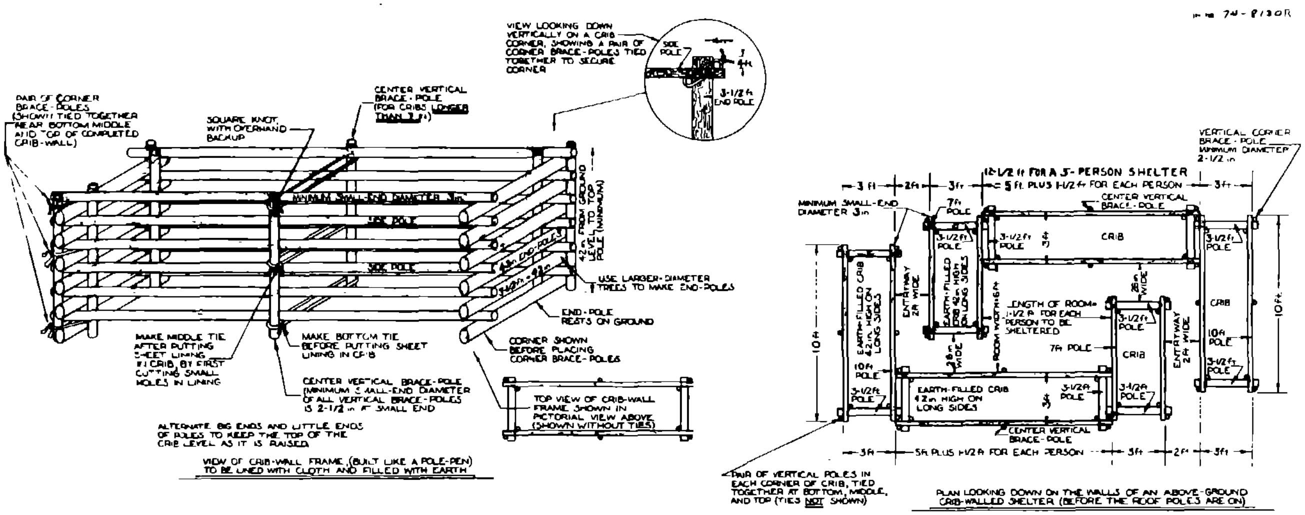
VERTICAL SECTION (CUT AWAY) OF AN ABOVE-GROUND DOOR-COVERED SHELTER

VERTICAL SECTION (CUT AWAY) ACROSS AN ABOVE-GROUND DOOR-COVERED SHELTER

PLAN LOOKING DOWN ON AN ABOVE-GROUND DOOR-COVERED SHELTER SIZED FOR 4 PERSONS (PROVIDE ONE ADDITIONAL ROOF DOOR FOR EACH PERSON BEYOND 4)

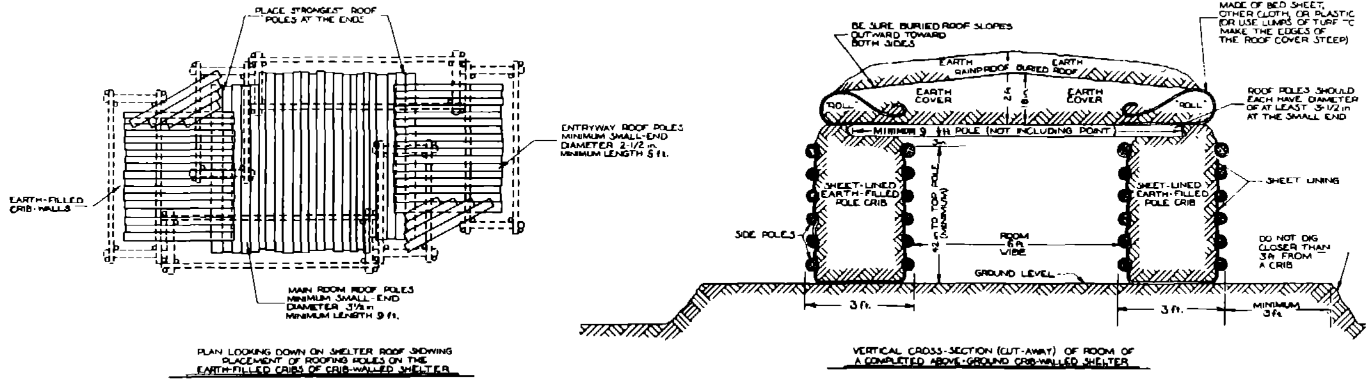
DIAGRAMS SHOWING STEPS TO MAKE EARTH-FILLED ROLLS FOR AN ABOVE-GROUND DOOR-COVERED SHELTER

Fig. 7.6. Aboveground door-covered earth roll shelter.



VIEW OF CRIB-WALL FRAME (BUILT LIKE A POLE-PEN) TO BE LINED WITH CLOTH AND FILLED WITH EARTH

PLAN LOOKING DOWN ON THE WALLS OF AN ABOVE-GROUND CRIB-WALLED SHELTER (BEFORE THE ROOF POLES ARE ON)



PLAN LOOKING DOWN ON SHELTER ROOF SHOWING PLACEMENT OF ROOFING POLES ON THE EARTH-FILLED CRIBS OF CRIB-WALLED SHELTER

VERTICAL CROSS-SECTION (CUT-AWAY) OF ROOM OF A COMPLETED ABOVE-GROUND CRIB-WALLED SHELTER

Fig. 7.7. Aboveground Crib-walled shelter.

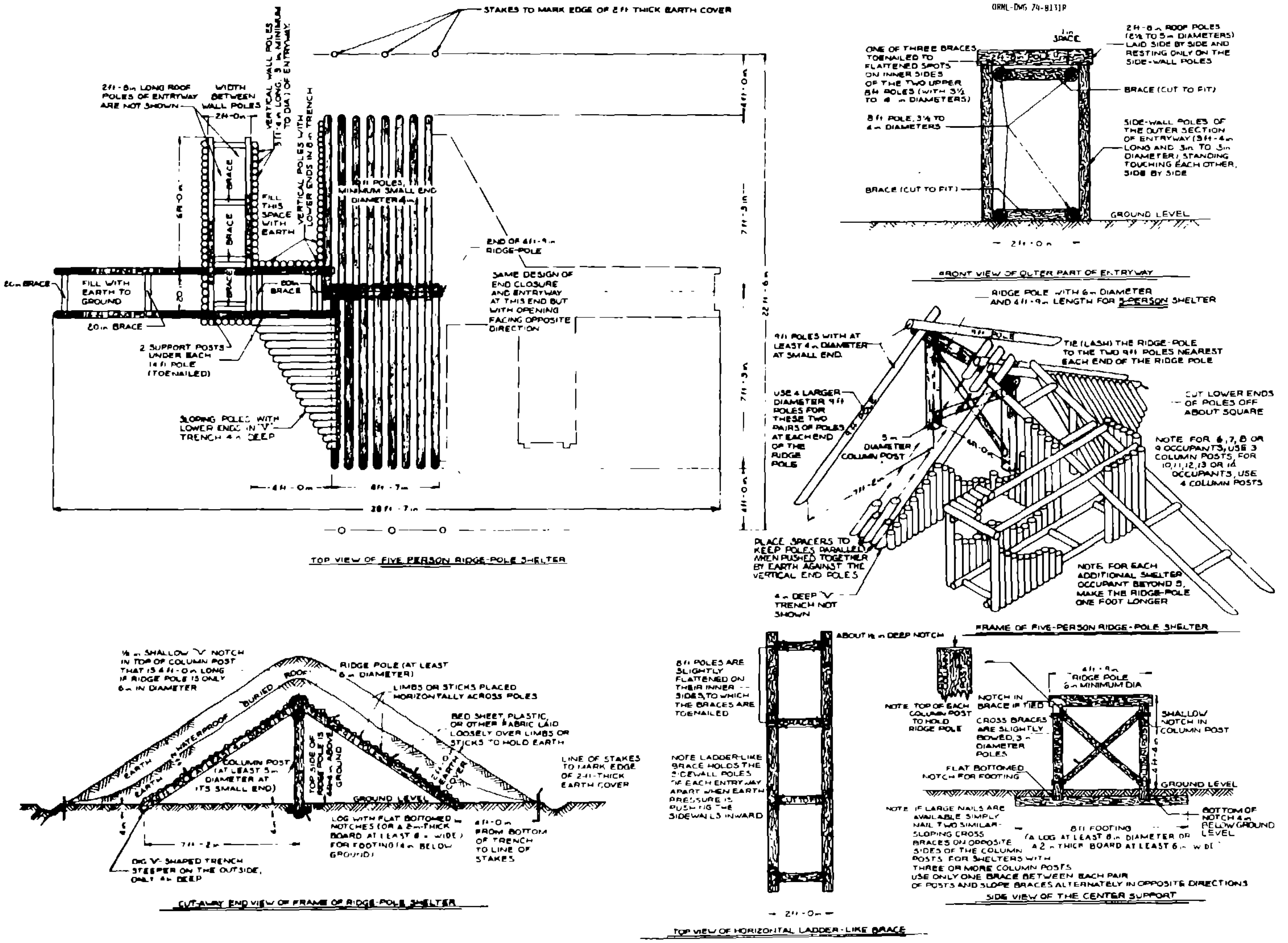


Fig. 7.8. Ridge-pole shelter.

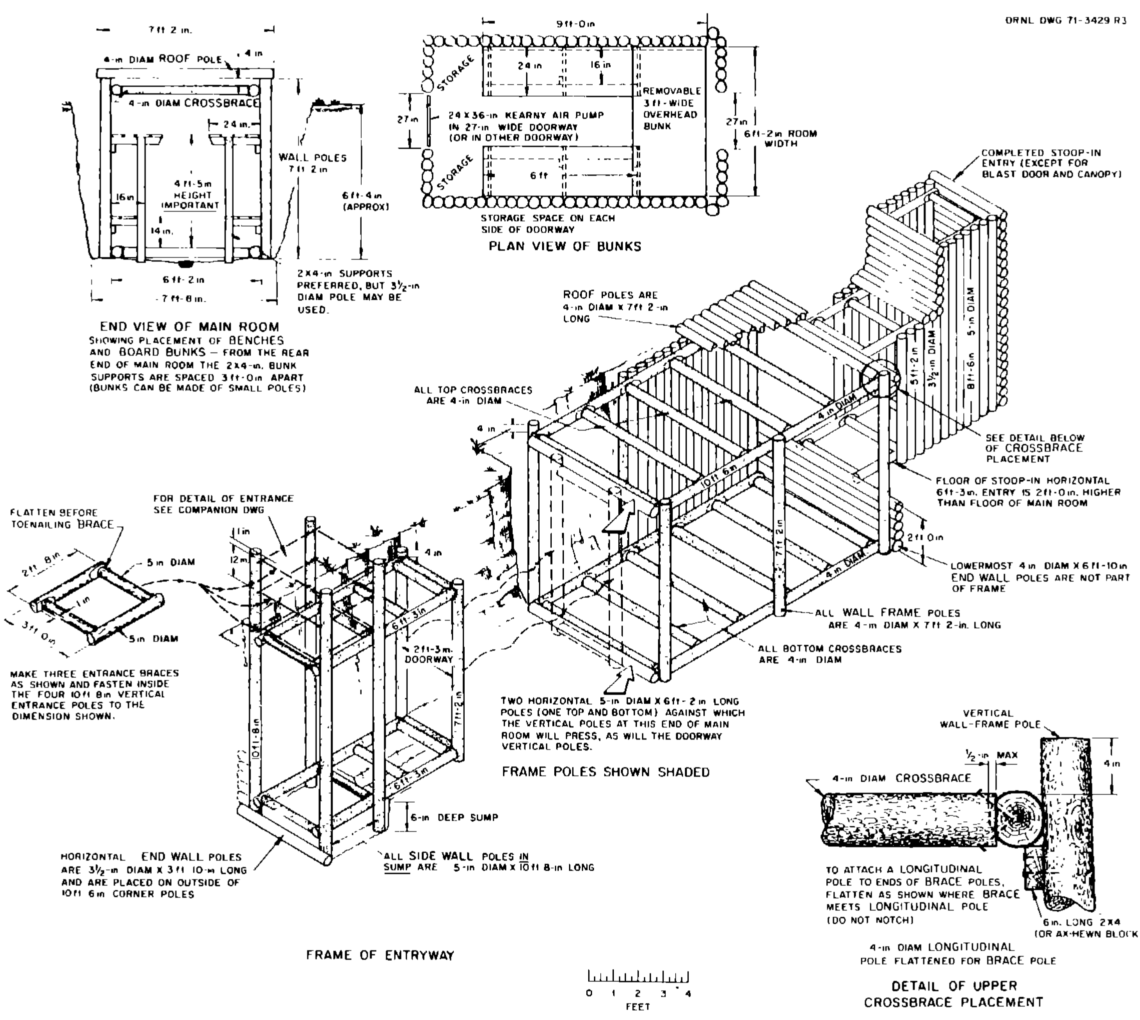
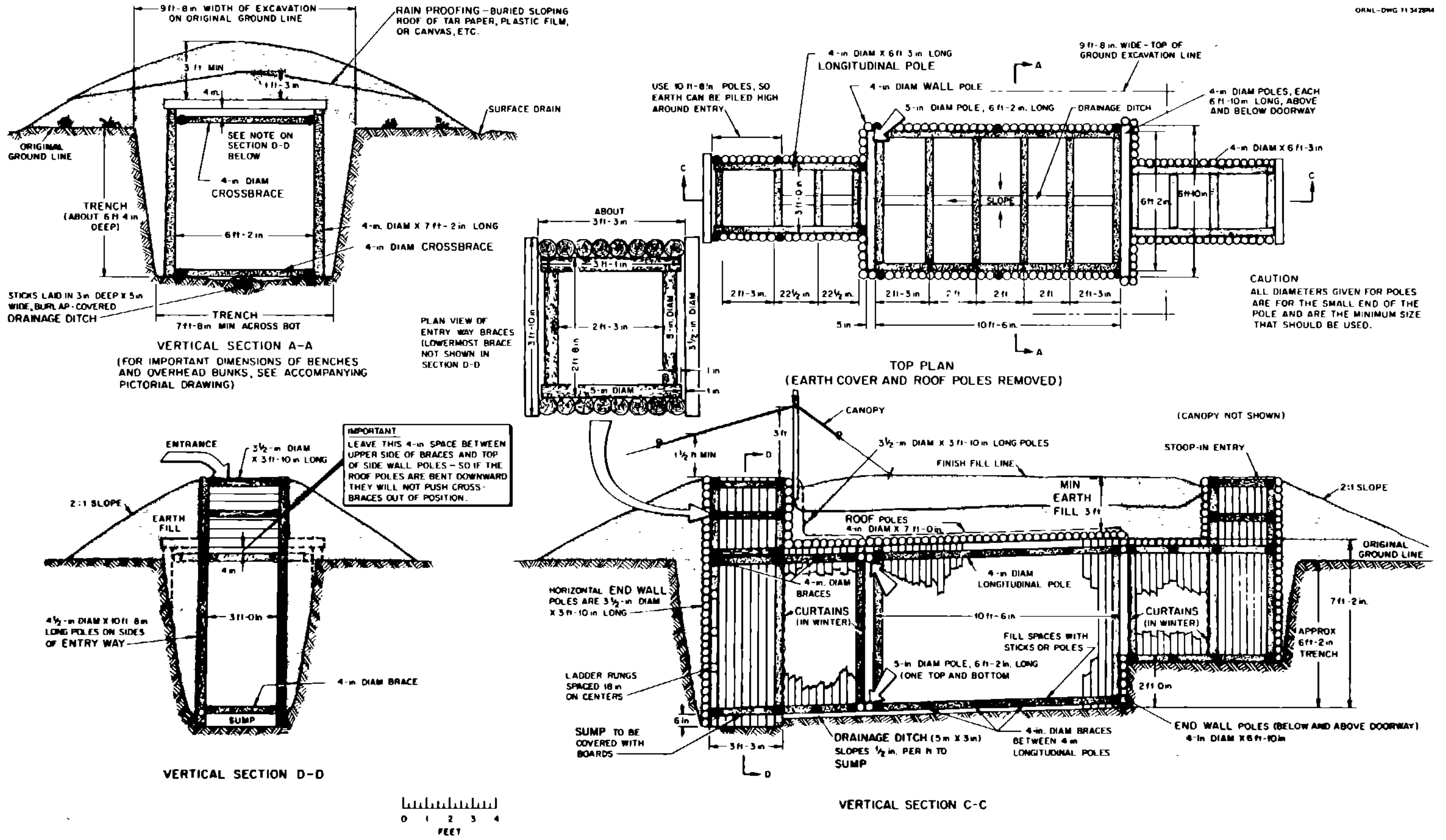


Fig. 7.9a. Small-pole shelter.



VERTICAL SECTION A-A

(FOR IMPORTANT DIMENSIONS OF BENCHES AND OVERHEAD BUNKS, SEE ACCOMPANYING PICTORIAL DRAWING)

TOP PLAN

(EARTH COVER AND ROOF POLES REMOVED)

CAUTION
ALL DIAMETERS GIVEN FOR POLES ARE FOR THE SMALL END OF THE POLE AND ARE THE MINIMUM SIZE THAT SHOULD BE USED.

IMPORTANT
LEAVE THIS 4-in SPACE BETWEEN UPPER SIDE OF BRACES AND TOP OF SIDE WALL POLES – SO IF THE ROOF POLES ARE BENT DOWNWARD THEY WILL NOT PUSH CROSS-BRACES OUT OF POSITION.

VERTICAL SECTION D-D

VERTICAL SECTION C-C

Fig. 7.9b. Small-pole shelter.

ready instructional materials. The preparation has been done with the publication of Nuclear War Survival Skills, an Oak Ridge National Laboratory survival book, by Cresson Kearny (1979). The construction experiments show that the shelters can be built, and Cristy (July 1973) has shown that the materials for their construction are available in most parts of the country. Field experiments have demonstrated that these shelters provide an excellent chance of surviving at least fallout effects of nuclear weapons.

A disadvantage of these shelters is that they must be built in a crisis and thus require advance warning. Most of the designs are for wood construction. In parts of the country where most people live, there is enough rain to cause wood in contact with soil to decay over a period of months (shelters constructed of treated wood are usually made uninhabitable by vapors from the treatment chemicals).

No matter what policy is adopted by the Federal Emergency Management Agency concerning shelter, as long as only a few Americans are equipped with permanent shelter, this technology will remain an option in the event of a severe international crisis.

For additional information on expedient shelter, the following references are suggested: Carre (1974); Davis (1958); Hoot et al. (1974); Kennedy, Ball, Hoot, and Rieck (1974); Knott, Albright, Isenberg, and Kummer (1965); Nash et al. (1984); Ostroukh (1974); Russel and York (1984).

7.4 CAVES, MINES, AND TUNNELS

Mines and caves are potentially a very important source of shelter space in many parts of the country. They provide an extremely high fallout protection factor, and if people stay well back from the entrances, considerable protection against blast. Krupka (1965), in his seminal work, estimated a potential of 2 to 3 million spaces in tunnels, 4 million spaces in caves, and a potential for up to 100 million spaces in mines (60 to 70 million in limestone mines, 20 to 30 million in salt mines, and 5 million spaces in gypsum and sandstone mines).

The National Limestone Institute estimated in 1962 that one-third of the present open-pit mines could be converted to underground operations at a cost (in 1962) of \$0.25 per ft^3 of rock. This would produce bare shelter space for between \$21 and \$50 per occupant (in 1985 dollars). Krupka (1965) estimates that a program costing \$200 million (in 1985 dollars) could generate 10 million spaces per year. A crash program could generate 60 million spaces per year; it might generate 100 million spaces in 18 months. Converted open-pit limestone mines would be especially desirable because they tend to have large walk-in entrances.

There is much mined-out space in salt mines at depths of several hundred to a few thousand feet that is accessible only by elevators. The elevators in many cases hold only a few tens of people and take several minutes for a trip. Construction of adequate entrances to this space would be very expensive.

A number of studies have been conducted on ventilation, lighting, and sewage disposal in mines pressed into use as shelters in a crisis (Wright, York, Johnson, and Laney, 1976; Wright, Hill, McKnight, and York, 1975). The addition of ventilation, light, water, and sewage disposal to mines for shelter use would require a modest investment.

Recently Wright and his co-workers (Wright, Chessin, Reeves, and York, 1983), using available data bases from the Bureau of Mines, compiled a National Underground Mines Inventory in which they estimated the number of shelter spaces by county. While they did not provide a total of these spaces for the nation in their reports, their data were subsequently entered into the FEMA computer system. A total of 34,764,000 spaces was computed. Some counties show a considerable surplus of mine spaces over what would be needed for their population,even including relocatees. The report recommends that in these areas the assignment of population to counties should be re-examined to make use of the extra space.

The conversion of open-pit limestone mines to underground mines in the vicinity of shelter-deficient populations should also be re-examined. This appears to be a low-cost method of developing high-quality shelter space. Developing peacetime uses of the space, as has been done in Louisville, Kentucky, (Ullrich and Hagerty, 1984) and in the Kansas City underground (Ward, 1981), could make the conversion economically self-sustaining.

7.5 DUAL-USE SHELTER

As is indicated by the size of the bibliography for this report, there exists a substantial body of research on where and how to construct blast and fallout shelters. However, the cost of shelter construction still remains an obstacle to public acceptability and to Federal government support of shelter construction on a scale sufficient to provide adequate protection for even a small fraction of the American population.

Previous studies (as summarized by Chester and Holladay, 1983) have indicated a wide range for the cost of shelter; even the most economical blast shelter designs from various studies have costs ranging from $300 per space (or per occupant) to almost

$3000 per space. Strope, Devaney, Laurino, and Wengrovitz (1985) have estimated the added cost of providing fallout shelter in new basement construction to be about $5 per ft^2 or $50 per space. Recent efforts at reducing the cost of blast shelter to a more attractive level have proven that this task is more difficult than was expected (Barber and Sisson, 1985; Carroll, Farahti, and Gallaher, 1985).

There are two ways to reduce the apparent cost of any commodity: (1) make it cheaper, or (2) make some other person or activity pay for it. This latter method is sometimes known to economists as "cost displacement." This is an old concept in the provision of civil defense shelters and has also been called "slanting" and "dual-use." The dual-use concept takes advantage of the fact that the structural envelope of the shelter would have been constructed anyway due to the peacetime function of the structure. Thus, the total cost of the shelter comprises only those additional items which provide the required protection from fallout and/or from blast.

Previous protective structure studies have developed costs and cost comparisons for blast and fallout shelter. The most significant findings of those studies are presented below. In order to compare accurately the cost figures from those previous studies to each other, each set of cost estimates was updated to 1985 dollars using the R.S. Means "historical cost index" (Godfrey, 1985). This index was applied as a simple multiplication factor to convert earlier construction costs to January 1985 values. This is an accepted method within the construction industry and is used to compare costs between one year and another; however, since the index includes only a weighted average of typical construction material costs and labor rates, comparing costs between various designs and/or moving costs across a long time period may introduce errors.

7.5.1 Dual-use Fallout Shelter

Early civil defense studies were quick to identify certain types of structures as candidates for the addition of dual-use shelter for protection from fallout. Schools, community centers, and parking garages were the kinds of structures which were needed for use throughout the United States, and they were generally located in areas where large numbers of people could quickly occupy such shelters. These early studies also recognized that the addition of a low-cost shelter system (via the economies of dual-use) to necessary future construction had the potential for providing large amounts of shelter space to the U.S. population in a reasonable period of time.

Schools and community centers are still good candidates for such shelter construction, since these are public structures which are usually constructed with the endorsement of a local population in cooperation with its local government. In addition, these types of structures are colocated with the residential population. The chief drawback to parking garages is that their peacetime use is economically competitive only in very highly developed areas, such as in downtown cities, and this usually presents a rubble problem in an attack. In suburban or industrial park areas, land is sufficiently inexpensive so that the economical solution to parking is acres-upon-acres of blacktopping.

Basically, two techniques can be used in the design and construction of dual-use fallout shelter: barrier shielding and geometry shielding. These two concepts are discussed and illustrated in Sect. 4.2. Barrier shielding places a mass between the radioactive source (fallout) and the shelter occupants. This mass attenuates or reduces the amount of radiation which passes through. Any normal construction material can be used as barrier shielding; however, concrete and brick provide better shielding than lightweight materials, such as wood or glass. Geometry shielding places the shelter occupants out of the direct path of the radiation or at some distance from the source. Locating the shelter in a basement is one example of geometry shielding, since the contribution of the radiation from the fallout on the ground is small (due to the barrier shielding of the surrounding earth). The effect of gamma radiation can also be lessened as the distance from the source is increased. Utilization of the central core of a building or the upper floors of a high-rise structure as dual-use fallout shelter takes advantage of this principle.

The most complete set of cost data for dual-use fallout shelters is contained in six reports published by the Office of Civil Defense (1965, February 1966, July 1966, June 1967, December 1967, 1971). These reports contain construction details and comparative cost data for the actual construction of dual-use fallout shelter in 91 different structures which are located in at least 35 different states. A minimum fallout protection factor of 40 was designed into these shelters; some shelters had a fallout protection factor in excess of 1000. All of these shelters were added during the original construction of the structure. All types of structures are included: schools, parking garages, banks, libraries, churches, dormitories, office buildings, industrial facilities, and a home for the aged.

From the cost information contained in these six Office of Civil Defense reports, the additional (or incremental) cost of including fallout shelter in new construction can be obtained. In over one-third of the structures (36 of 91), dual-use fallout shelter was provided with no increase in cost of the construction project. That is, the added cost of dual-use fallout shelter for these 36 structures was $0.00. At least 25 of these shelters were provided in basements or partial basements. The remainder were provided as part of the interior core of the main structure.

The average cost of shelter for all 91 structures was about \$3.50 per ft^2 of shelter space (in 1985 dollars). Using a value of 10 ft^2 for each shelter occupant, the incremental cost of dual-use fallout shelter becomes about \$35 per space (or per occupant) in 1985 dollars. This number includes the average of both basement and other types of shelter. As noted above, it appears possible to provide basement fallout shelter for even less than \$35 per space.

For additional information on dual-use fallout shelters, the following references are suggested: Cristy (October 1968); Dembo and Baldwin (1967); Eberle M. Smith Associates, Inc. (1962); Lamb et al. (1964); Lutz, Lynch, and Lutz (1972); Office of Civil Defense (August 1962b, November 1962a, November 1962b, November 1963); Oklahoma State Department of Education (1978); Public Health Service (1962).

7.5.2 Dual-Use Blast Shelters

Previous studies have concluded that dual-use fallout shelter (without blast protection) can be provided for a relatively small additional expense over the cost of the original building. On the other hand, investigators of aboveground, dual-use blast shelter have concluded that such structures are extremely expensive because of the large amounts of reinforced concrete required to provide blast and radiation protection. For example, Bennedsen (1962a) conducted a study which modified the design of five existing buildings (with construction dates between 1958 and 1962) in the Norfolk, Virginia, area to include 30-psi fallout shelter into the first floor plan of each building during its construction. The average additional cost of such structures over that of the conventional design was \$49 per ft^2 of shelter space (in 1985 dollars), which was an increase of about 50% over the square foot cost of the conventional building.

Additional designs and cost estimates for blast-resistant, aboveground structures can be found in Ammann and Whitney (1960) and in Longinow (1967). The reader is cautioned that these aboveground designs, while they might be adequate for protection from fallout radiation, probably do not provide sufficient protection from the initial nuclear radiation of intermediate-yield nuclear weapons at their respective design overpressure levels.

Longinow's report (1967) is of particular interest here, since it provides a compendium of protective shelter studies which relate to dual-use structures. Both aboveground and belowground structures are considered. Included are reviews of comparative cost studies for schools, community centers, expressway grade separations, parking garages, warehouses, administration buildings, office buildings, and vehicular tunnels. Most of these studies are concerned with fallout protection only, or with the additional cost of blast shelter over and above the cost of fallout shelter. Surprisingly, the added cost of basement blast shelter over that of a conventional basement structure seems to have been largely ignored through about 1967.

Under the U.S. Department of Defense, the Office of Civil Defense (August 1962, September 1962a, September 1962b, March 1963, April 1963, June 1963) developed most of the early information about the cost of blast shelter. Again, this cost information compares the price of blast protection to the price of fallout protection. If one can assume that the cost of fallout protection in underground structures is negligibly small (see Section 7.5.1), then a meaningful comparison can be made. Otherwise, such incremental costs must be understood to represent only a portion of the total added cost of blast shelter.

Beginning in about 1967, interest in the incremental cost of blast shelter seemed to increase. Longinow, Kalinowski, Kot, and Salzberg (1971a, 1971b); Longinow, Ojdrovich, Bertram, and Wiedermann (1973); and Murphy, Rempel, and Beck (1975) contributed to the development of not only blast-resistant shelter designs, but also detailed cost comparisons.

Information on the incremental cost of blast shelter, over and above the cost of conventional basement construction has been taken from the above reports, translated into 1985 dollars (see Section 7.5 for a description of the cost conversion method), and summarized in Figs. 7.10 and 7.11. More specific design details are discussed below.

The shelter concept illustrated in Fig. 7.12 (Office of Civil Defense, August 1962 and June 1963) is a basement-type, reinforced-concrete structure which is designed to provide protection against the effects of megaton-size nuclear weapons. The structure is designed to serve a dual function [e.g., a community center (for civil administration, religious services, town assemblies, and/or recreation events) during normal occupancy and a shelter during emergencies]. The structural design details are as general as such details can be. A flexible structural system within an economical square form was selected for the purposes of illustration only. The layouts were intended to be rearranged to suit the requirements of the individual user. Typical designs are illustrated in the reports for shelter capacities of 100, 500, and 1000 persons. Blast protection for overpressures of 5, 25, and 50 psi were included for each of the designs.

Two other reports by the Office of Civil Defense (September 1962a and April 1963) describe conceptual designs for parking garages which are one-story, belowgrade, reinforced-concrete structures (See Figs. 7.13a and 7.13b) that will provide protec-

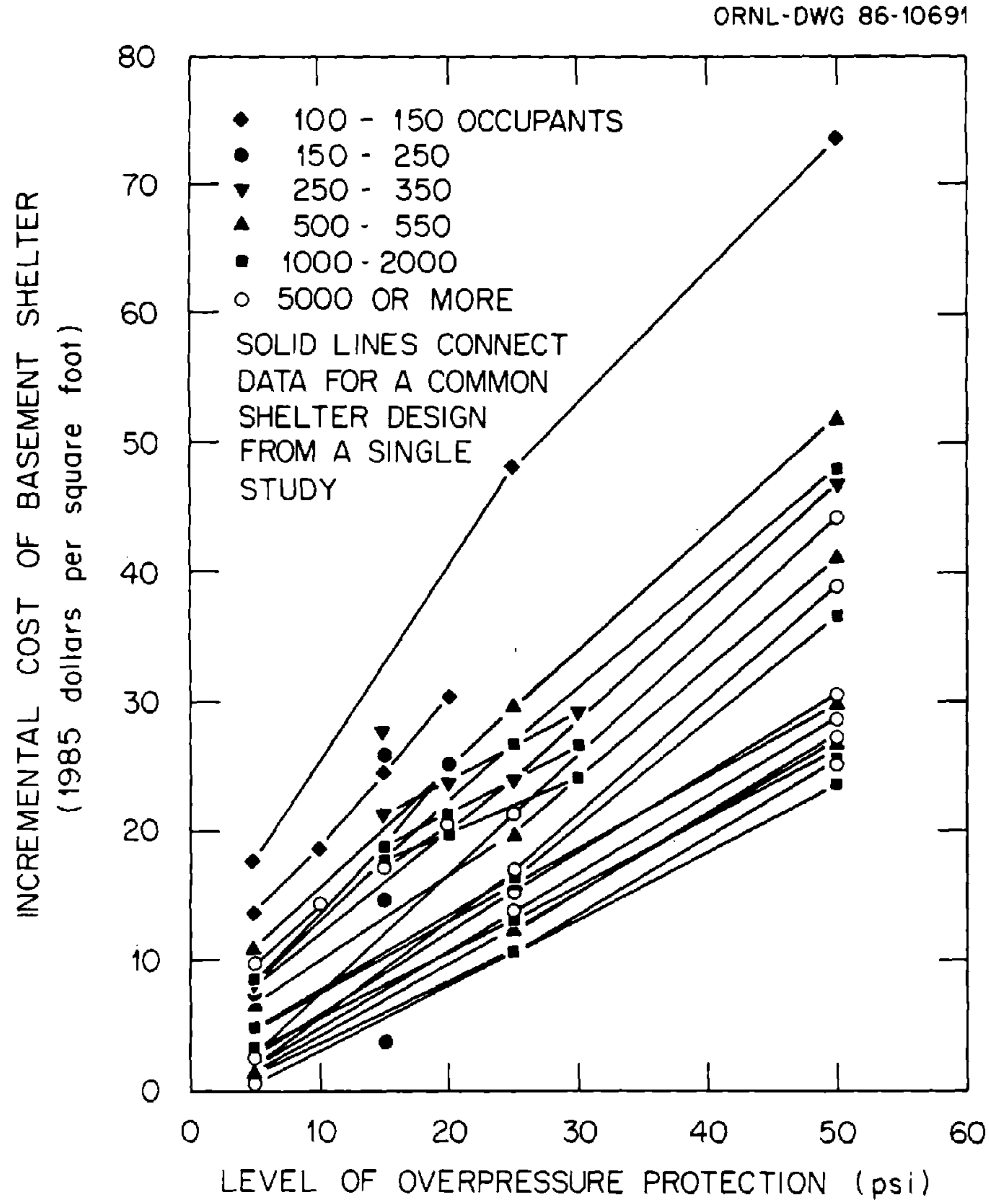


Fig. 7.10. Incremental cost of blast shelter as a function of designed overpressure protection.

ORNL-DWG 86-10692

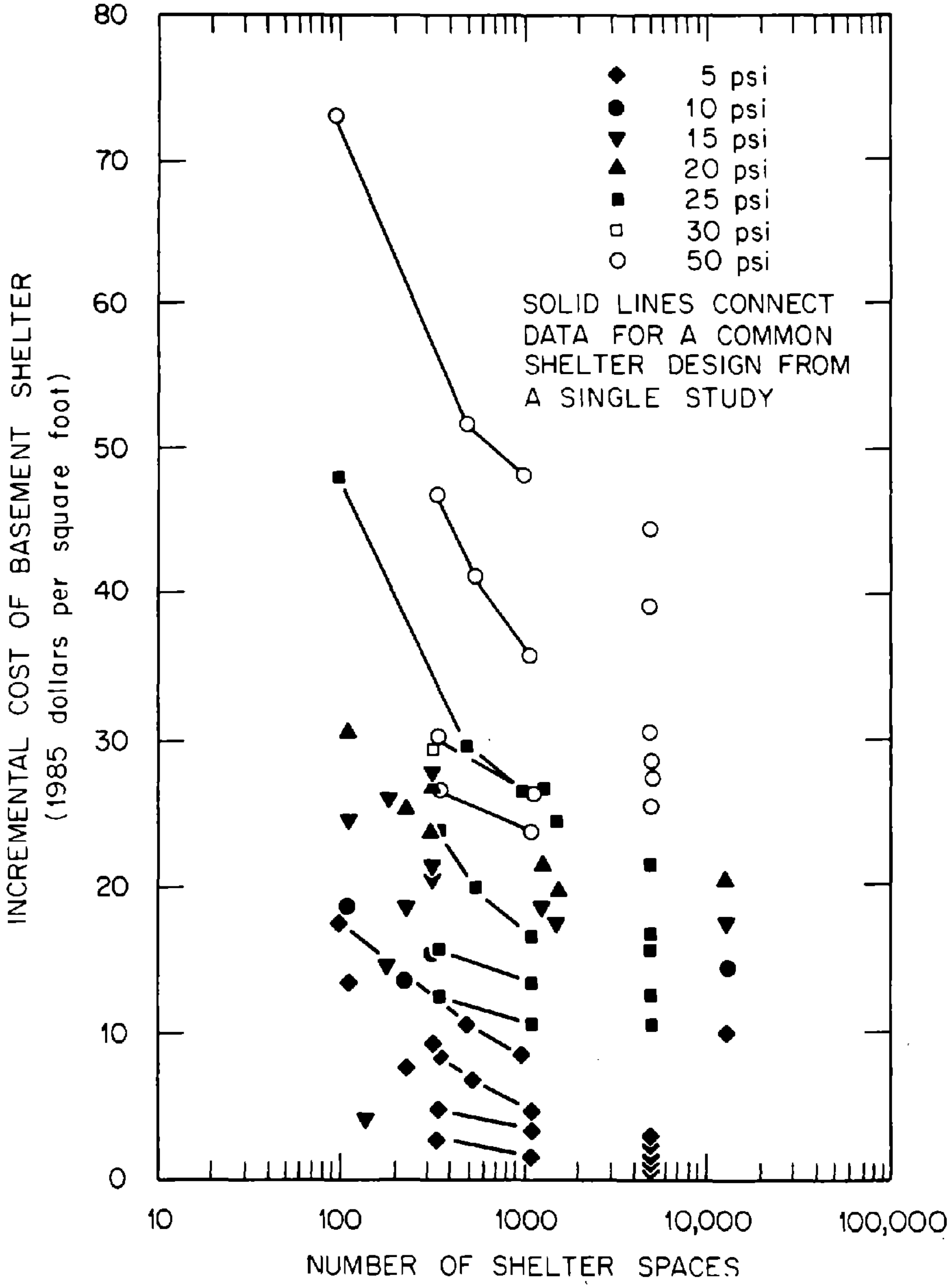


Fig. 7.11. Incremental cost of blast shelter as a function of designed shelter capacity.

ORNL-DWG 86-11140

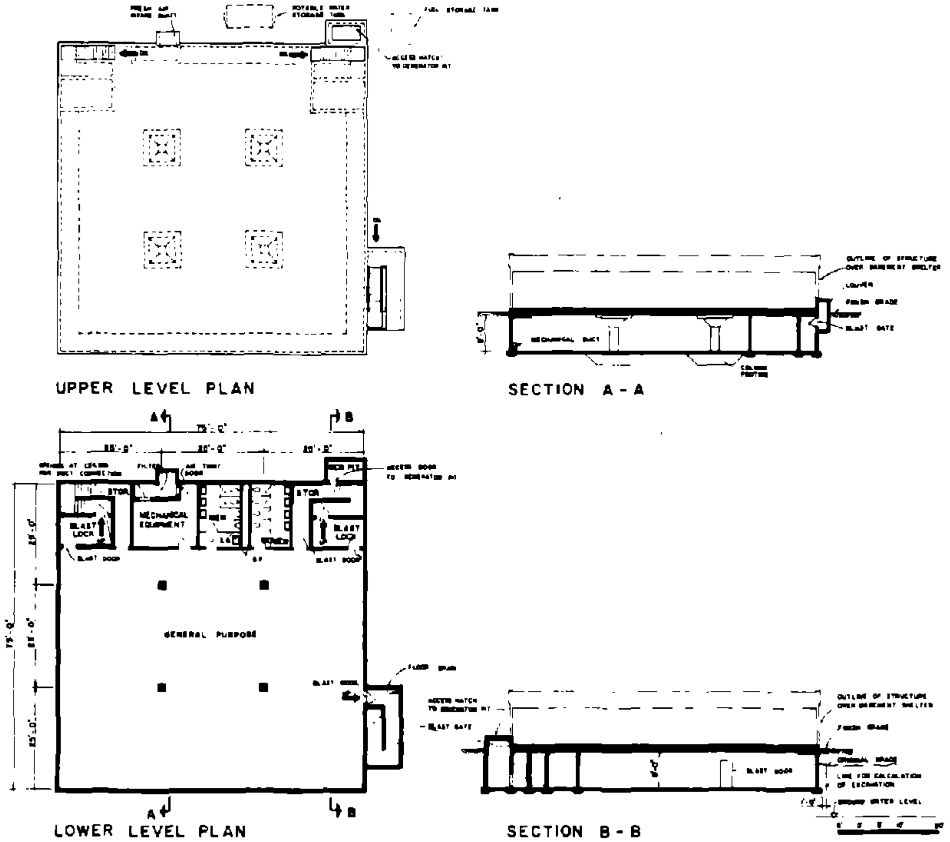


Fig. 7.12. Dual-use basement community center blast shelter.

ORNL-DWG 86-11138

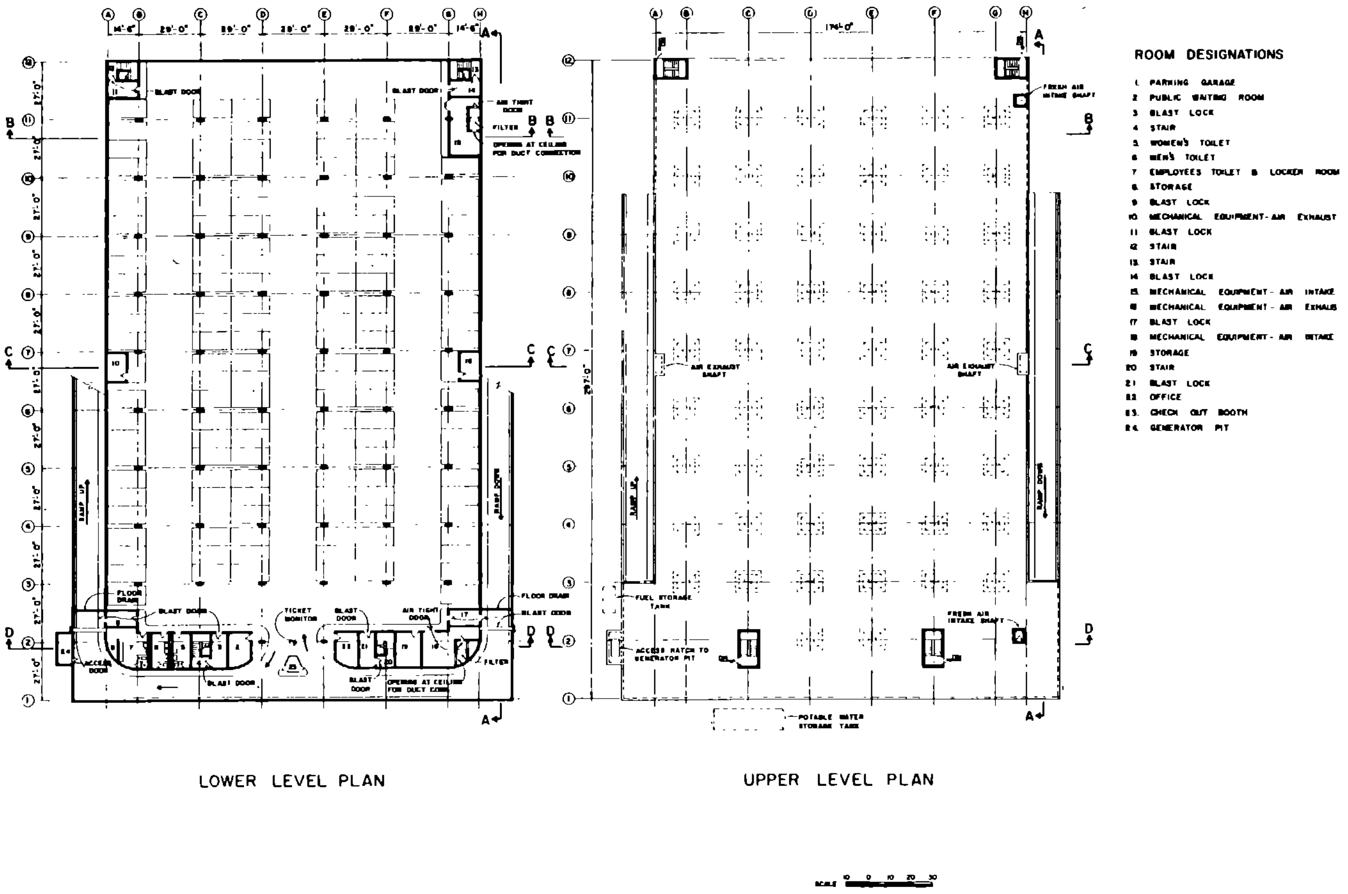


Fig. 7.13a. Dual-use parking garage/blast shelter.

ORNL-DWG 86-11139

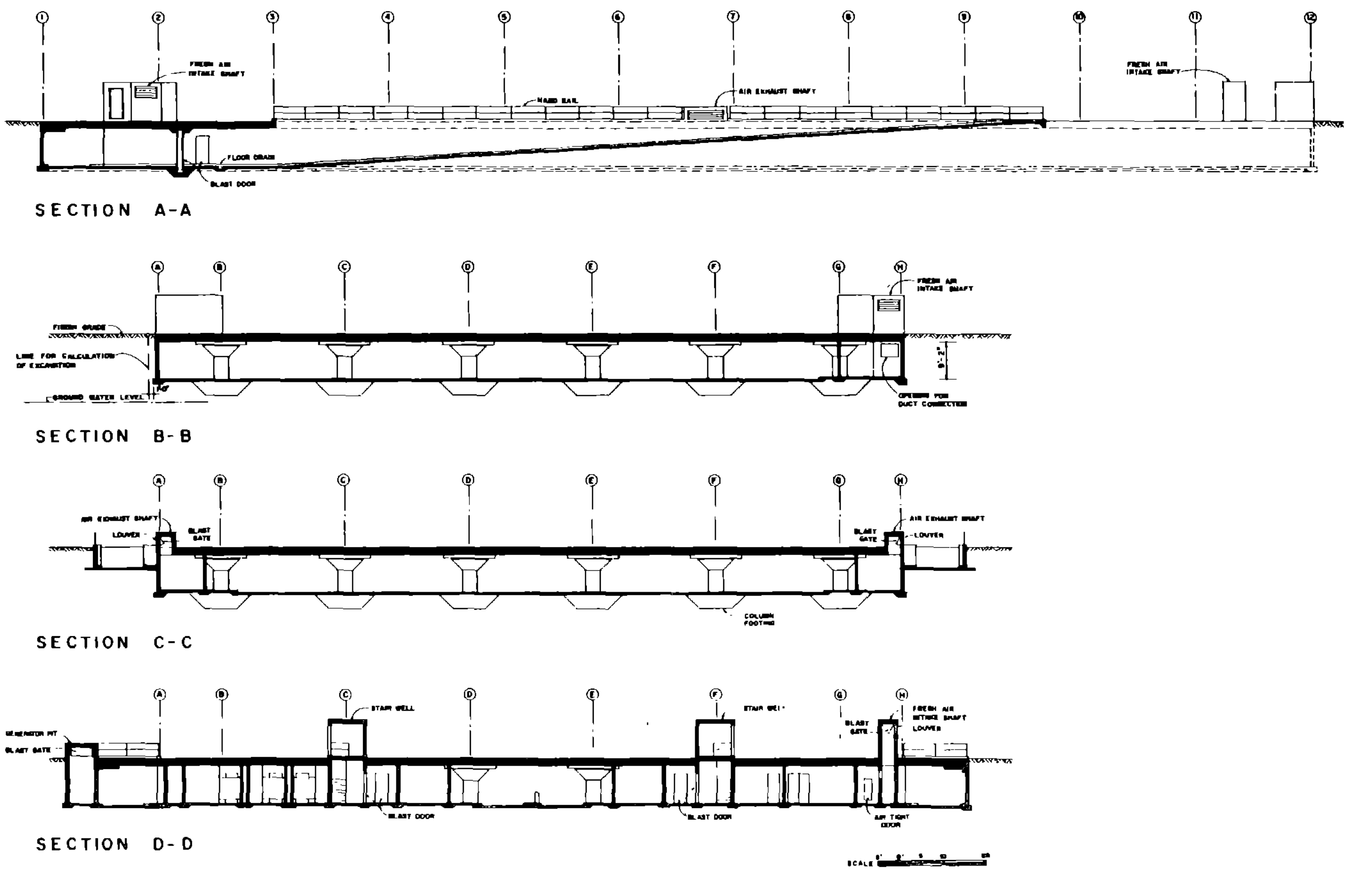


Fig. 7.13b. Dual-use parking garage/blast shelter.

tion against the effects of megaton-size range weapons. The structures are based on multiples of a 29-ft by 27-ft bay area proportioned to the dimensions of an average city block. Each structure contains parking facilities for 150 cars during normal operation and shelter space for 5000 occupants during emergencies.

Two parking garage designs are considered. One garage is to be located below a parking lot; its roof slab serves as a deck. The other garage is to be located beneath a city park; its roof slab is modified to support a minimum of 3.5 ft of soil for landscaping. The blast shelter roof slab thicknesses for both structures were 12 in. for 5 psi, 21 in. for 25 psi, and 36 in. for 50 psi overpressure resistance.

Additional reports by the Office of Civil Defense (September 1962b and March 1963) illustrate conceptual shelter designs which are basement-type, reinforced-concrete structures (See Fig. 7.14). The structures are designed to function as school classrooms under normal occupancy and, in the event of emergency, as shelter areas for the total school population, including that from the unprotected classrooms above ground.These basement shelters are single-level structures with the roof slabs at grade level. Typical designs are illustrated for shelter capacities of 350, 550, and 1100 persons. Designs for 5, 25, and 50 psi overpressure levels are included.

Bruce et al. (1965) summarize a comprehensive study and analysis of the capabilities of 26 award-winning entries from the National School Fallout Shelter Design Competition to provide protection against effects of nuclear weapons other than those associated with fallout. In cases where the original fallout shelter designs were deficient in providing such additional protection, recommended design changes and their associated costs were developed. Both aboveground and belowground structures were evaluated; although, no specific design information is given in the report. The schools were originally designed to provide a fallout protection factor of 100. Structural analyses indicated that the inherent blast protection provided by these school shelters varied from approximately 0 to 2 psi overpressure resistance. With minor modifications to each design, additional protection from thermal and blast effects could be obtained for a small additional cost. The report indicates that the level of overpressure resistance could be increased to approximately 10 psi for an average incremental cost of \$3.20 per ft^2 of shelter space (in 1985 dollars). The report does not indicate how much, if any, the cost of fallout shelter added to the original, conventional design.

Longinow, Kalinowski, Kot, and Salzberg (1971a and 1971b) describe two types of dual-use structures--school basements and parking garages. Essentially, these reports update the 1962 Office of Civil Defense shelter cost estimates using the original

ORNL-DWG 86-11137

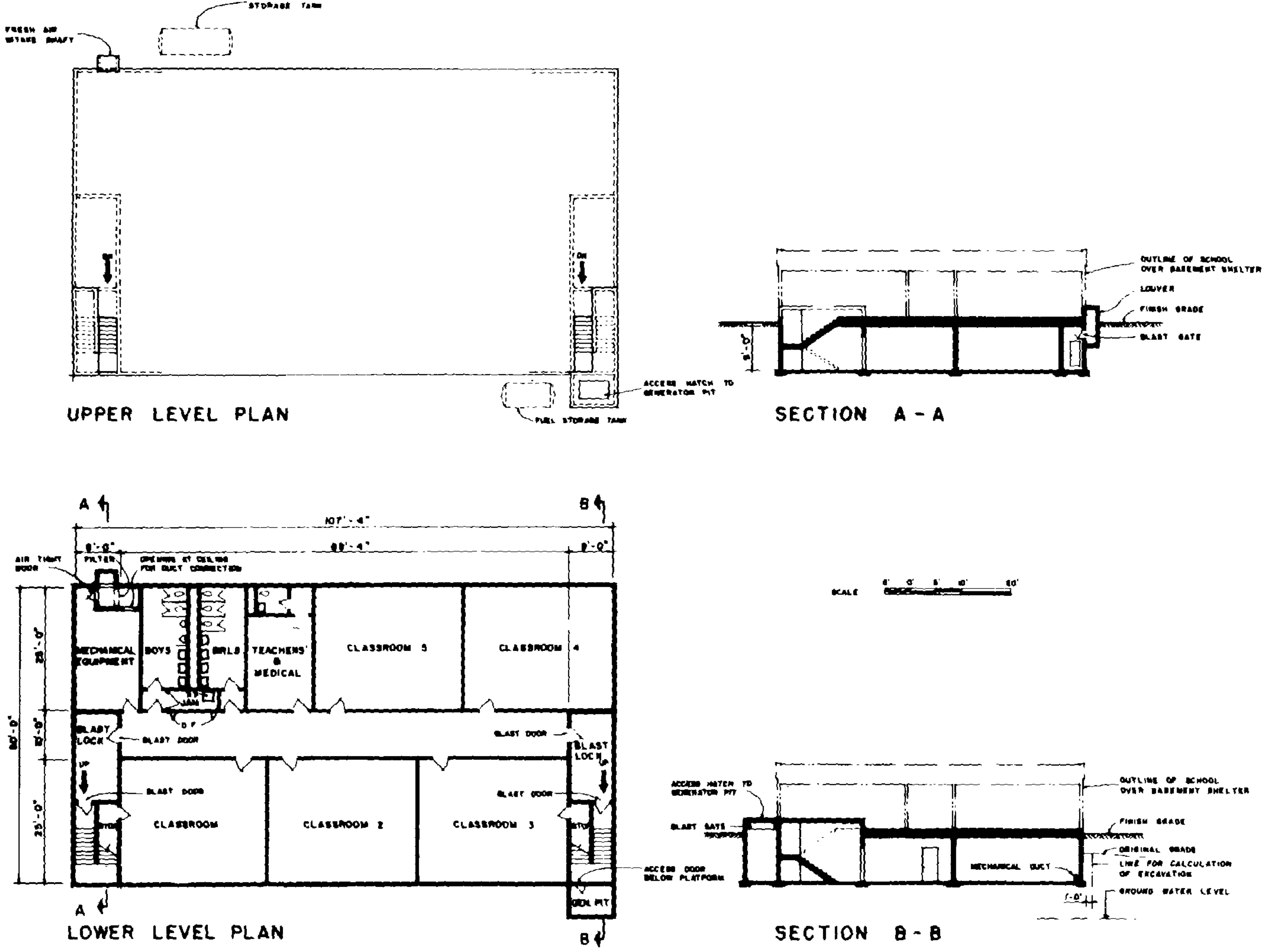


Fig. 7.14. Dual-use basement classrooms/blast shelter.

1962 designs (see above). The reports state that the original "fallout shelter only" design was similar enough to a conventional structure that it could be used as the reference for the blast shelter cost comparisons.

A later report by Longinow, Ojdrovich, Bertram, and Wiedermann (1973) develops cost estimates from original designs of both an aboveground shelter and a basement shelter, either of which would be suitable for addition to a small one-floor office building or other small professional structure during new construction. The basement shelter, with its 15-in. roof slab at grade level, was designed to withstand the blast effects of a 15 psi overpressure from a megaton-size weapon. An emergency generator and lighting fixtures were included in the cost estimate. This report also compares the cost and survivability for aboveground shelters and concludes that the belowgrade shelter variation appears to be a better alternative.

Murphy, Rempel, and Beck (1975) completed a feasibility study containing information which might be incorporated into a "guidebook" on dual-use shelter design. This report is by far the most extensive and elaborate on basement shelters in new construction; several designs (along with the appropriate design philosophy and equations) and cost estimates are presented. Four case studies of existing buildings in Georgia and North Carolina were developed. The report includes cost extrapolations to several different levels of protection from 5 psi up to 30 psi.

The environment of interest in the Murphy study was 15-psi overpressure from a 1-MT weapon. Initial nuclear radiation from a 200-kT weapon was also considered. At the 15-psi level, an (unshielded) initial nuclear radiation dose of 450 rads was used in the designs. The designs included two types of shelters. One type of shelter was intended to be completely buttoned-up, prior to the blast. The other type of shelter was to be completely accessible for ingress until at least one full minute after the arrival of the blast wave. Murphy has updated his original shelter cost figures at least twice (Murphy and Beck, 1976; Appendix C in Strope, Devaney, Laurino, and Wengrovitz, 1985).

The summarized findings of the above reports appear and in Figs. 7.10 and 7.11. The data are for the additional (or incremental) cost, in 1985 dollars, of blast shelter over the original cost of the conventional building (i.e., for basement shelters which are added to new construction designs that already include a basement area). The data in Fig. 7.10 clearly illustrate the trend of higher shelter cost with increased levels of overpressure protection. Figure 7.11 identifies the trend that larger shelters cost less.

For a 30-psi level of overpressure protection, Fig. 7.10 indicates that the incremental cost of shelter space lies between

\$13.50 and \$53.50 per ft^2. Using a value of 10 ft^2 for each shelter occupant, the incremental cost of 30-psi blast shelter becomes \$135 to \$535 per space (or per occupant) in 1985 dollars, for an average of about \$335 per space. This average value does not take the apparent economy of larger shelter sizes into account.

For a 50-psi level of overpressure protection, Fig. 7.10 indicates that the incremental cost of shelter space lies between \$23.50 and \$73.50 per ft^2. Again, using 10 ft^2 for each shelter occupant, the incremental cost of 50-psi blast shelter becomes \$235 to \$735 per space in 1985 dollars, for an average of about \$500 per space.

In some of the blast shelter designs reviewed above, the thickness of the roof slab was determined solely by structural resistance to the specified blast overpressure. However, for some nuclear weapon environments of interest this may not provide sufficient shielding to insure protection from the initial nuclear radiation of small-yield nuclear weapons.

A recent report (Shaw, 1985) documents the U.S. government's effort to determine the cost of a slanted basement shelter during an actual construction project. Two structures to be built in the Washington, DC, area were reviewed as candidates for the addition of a proposed 15-psi dual-use basement blast shelter. This shelter was to be included as part of the original construction.

The basement shelter in the first structure (an 11-story office building) required substantial modification to the footings of the existing adjacent buildings. This structure was therefore removed from further consideration; nevertheless, a contract bid price for the shelter construction was developed. For the 1590-ft^2 shelter, the cost of adding shelter to the structure was \$112 per ft^2 of shelter space in 1985 dollars. If the footing modifications had been removed from the shelter cost, then the incremental cost of adding the shelter would have been \$64 per ft^2.

A shelter was actually constructed in the second structure (the National Rehabilitation Hospital). Construction began in mid-May 1984; the basement shelter occupied 2300 ft^2. Two contractor bids were received for this shelter: \$38.30 per ft^2 and \$61.70 per ft^2 (in 1985 dollars). Both bids reflect the added cost for the shelter space over and above the cost of the building without shelter; no reason for the wide variation in the two shelter costs is given in the report. Tests performed on a one-fifth-scale model of this shelter indicate that it is substantially overdesigned; only hairline cracks were observed in the roof of the model after exposure to 50 psi from a simulated 8-kT nuclear blast.

For additional information on dual-use blast shelters, the following references are suggested: Bennedsen (1962b); Cristy (October 1968, 1971, 1972, February 1973); Feinstein and Wingfield (1970); Lin, O'Donnell, Yauger, Burt, and Kling (1972); McGavin (1970); Murphy (1969, 1970a, 1970b); Smith and Lasky (1963); Stepenek (1970).

7.5.3 Earth-Sheltered Residences

"Earth-sheltering" is the term given to the practice of designing and constructing a residence or other small building in such a way that all or part of the perimeter walls and all or part of the roof are covered with earth. This can be done by siting the structure in a number of ways. The most popular method is to construct the building on a slope so that its rear wall is belowgrade (See Fig. 7.15). The front wall (usually facing south) is completely exposed and the end walls are all or partially earth-covered. The roof is usually earth-covered and extends naturally into the slope of the hill. The designs are normally intended to be solar heated through windows in the exposed south-facing wall. See Carmody and Sterling (1985) and Wade (1983) for a complete discussion of earth-sheltered housing design.

Earth-sheltered buildings are usually designed so as to conserve heating and air-conditioning energy, which they do very well. They also provide protection against violent storms, especially tornadoes, as well as other natural disasters (such as winter ice storms and brush or forest fires). Recognition of the effectiveness of earth-sheltered structures against tornadoes and cold weather is demonstrated by the map, Fig 7.16, of earth-shelter locations in the United States.

Concrete construction and earth-covering provide inherent fallout protection which in most cases is superior to that available in the basements of frame houses. With minor modifications to the designs, such as appropriate arrangement of interior solid walls, quite high levels of protection against radiation can be obtained in the rooms in the rear of the building (Chester, 1981, November/December 1981; Chester, Torri-Safdie, et al., 1984, 1985). For a few percent increase over the cost of a "conventional" earth-sheltered residence, a strengthened building can be constructed which has significant blast resistance and which can be upgraded to one or two atmospheres of blast resistance (Chester, Shapira, et al., 1983).

The disadvantage of earth-sheltered structures is that they cost 30 to 40% more than comparable conventional aboveground frame buildings (Shapira, et al., 1983). This increased cost is in the concrete construction and in the additional expense of running utility lines in conduit or service ducts inside solid

ORNL-Photo 1613-78

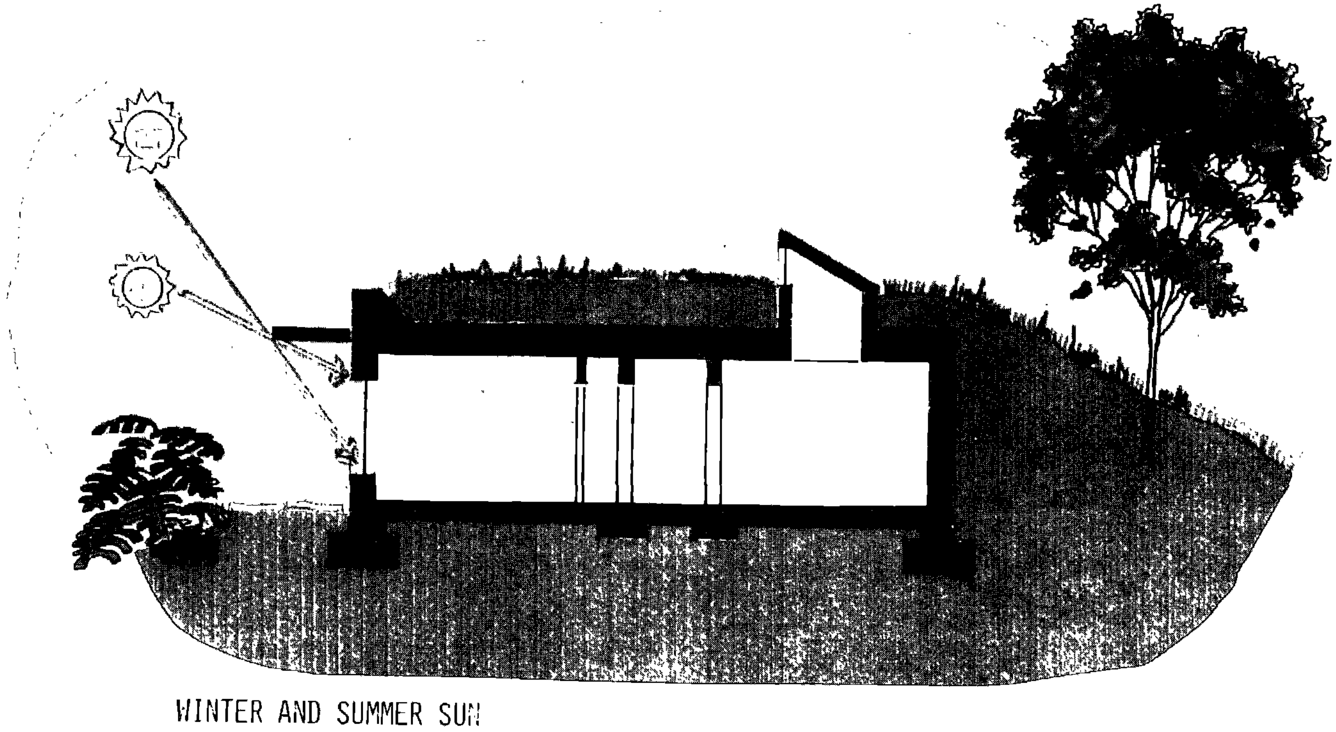
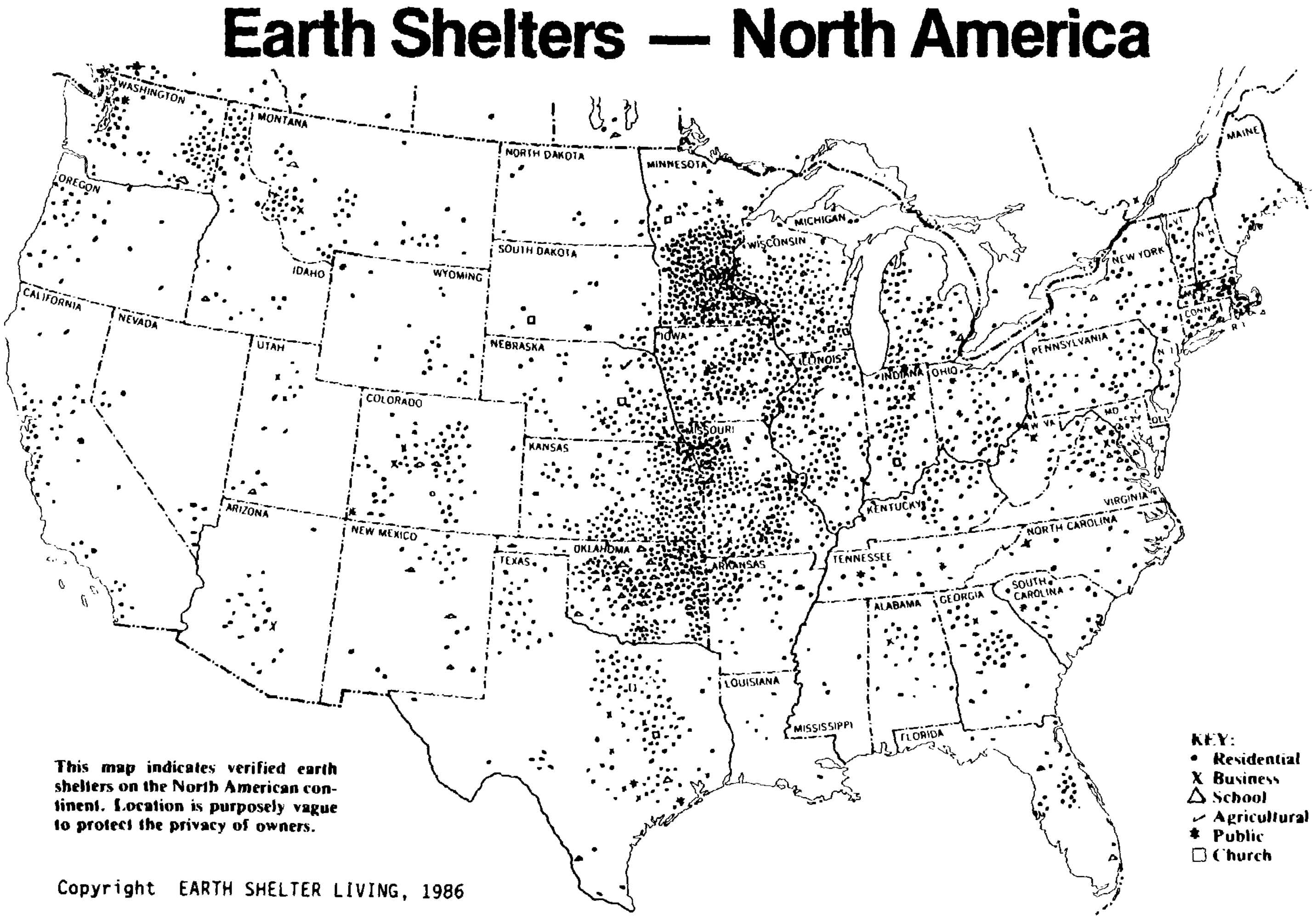


Fig. 7.15. Earth-sheltered housing concept.

ORNL-DWG 84-16268R



This map indicates verified earth shelters on the North American continent. Location is purposely vague to protect the privacy of owners.

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Fig. 7.16. Locations of earth-sheltered buildings in the United States.

concrete walls and roofs. If the cost problems could be surmounted, the U.S. housing industry, which can build close to 2 million houses a year, could construct enough underground housing in a single year to provide shelter for the entire U.S. population. Even a few percent of the houses constructed each year as dual-use earth-sheltered residences would add significantly to the national inventory of shelter space in a very few years.

It was estimated by Chester et al. (1985) that the cost of blast-slanted, earth-sheltered structures would be approximately \$70 per ft^2; this is approximately \$17.40 per ft^2 more than comparable conventional aboveground construction. If people were crowded into these buildings at the rate of 1 person per 10 ft^2, the incremental cost for 15-psi blast shelter would be approximately \$174 per space. This cost is quite competitive with other dual-use shelter costs.

The use of private residences for public shelter can raise some social, legal, and even constitutional problems, even if constructed with Federal subsidies.

For additional information on earth-sheltered residences, waterproofing underground structures, and policy issues for shared, underground shelter, the following references are suggested: Anderson (1984); Barker(1980); Barnard (1981); Burson and Borella (1961); Fairhurst (1976); Haaland (1983); Heck (1968); Hollon, Kendall, Norsted, and Watson (1980): Korrell (1979); Lane (1984); Logan (1984); Metz (1980); Moreland et al. (1981); Regional and Urban Planning Implementation, Inc. (1977); Sisson (1977, 1980); Sterling, Aiken, and Carmody (1981); Sterling, Carmody, and Elnicky (1981); Thorsen (1980); University of Minnesota (1980, 1981); Zaccor (1979).

7.5.4 Dual-Use Tunnel Systems

Boegly, Griffith, and Nelson (1969) developed a conceptual design and cost estimate for a dual-use tunnel adapted to provide blast shelters for White Plains, New York. The tunnel system was designed for an area which would have a daytime population of 20,000 and a nighttime population of 5000. By extreme crowding (3.5 ft^2 per occupant or 45 ft^3 per occupant) the daytime population could be accommodated in the shelter. The cost per occupant under these circumstances would be \$836 (in 1985 dollars). If civil defense standards of 10 ft^2 per person were required, the cost would very nearly triple to approximately \$2500 per occupant. The costs include food storage, ventilation and air conditioning requirements, and sanitation, with optional carbon dioxide removal and oxygen supply for 8 hours. The lower costs above do not include this long a button-up period.

Boegly, Griffith, and Nelson estimate the hardness of the tunnel system at 60 psi. Subsequent experience with the hardness of underground structures suggests that the hardness is probably in excess of 100 psi. The system in the above study is consistent with other slanted tunnel systems which have rather high costs per shelter space, unless extreme overcrowding takes place. Also, in common with other studies, this system is designed for an area of very high population density which can be effectively attacked with groundburst weapons.

A tunnel grid system constructed of 8-ft-diam concrete pipe was designed for Detroit by the firm of Holmes and Narver (Robbins and Narver, 1965; Narver and Robbins, 1965). The entrances on this design were very costly and complex. The cost per space for the system was $1722 in 1985 dollars. Holmes and Narver also conducted the design and cost estimate of the deep underground highway across town on Manhattan Island which could be adapted to a blast shelter (Perla and Haller, 1965). The structure for only peacetime use would cost $2.08 billion (in 1985). For an additional 2.2 billion (in 1985 dollars) 1.8 million shelter spaces could be created at a cost of $1229 per space.

For additional information on tunnels used as shelters, the following references are suggested: Cristy (1967a, November 1968, 1971); Heierli and Jundt (1983); Heierli, Jundt, and Kessler (1985); Hendrey et al. (1981); Newman (1966); Shimizu, Elder, Shepetys, and Williamson (1969); Shimizu, Snow, and Williamson (1969); University of Arizona (1965); Williams, Huffaker, and Abele (1967); Williams and Kennedy (1968).

7.6 DEDICATED SHELTERS

The term "dedicated" or single-purpose shelters is applied to structures whose primary function is to serve as a shelter against the effects of nuclear weapons. The term is used to differentiate these structures from "dual-use" structures whose primary purpose is some other function (such as a basement, school, or subway). Dedicated shelters do not have to make any compromises with regard to peacetime functions and can easily be designed for very high levels of protection. Without the peacetime use to defray the cost, dedicated shelters are generally much more expensive than dual-use structures.

The description of examples of dedicated shelters in this section are intended to be illustrative rather than exhaustive. For a more complete list of shelter designs and options, the following references are suggested: Allgood, Webb, and Swalley (1962); Baker, Heck, et al. (1964);Bauer (1981); Bigelow (1965); Central Mortgage and Housing Corporation (1959); Emergency Measures Organization (no date, 1961, 1962b); Federal Emergency Management Agency (1979, April 1980b, April 1980d, April 1980f);

FitzSimons (1957); Havers and Lukes (1964); Holmes and Narver (1960); Home Office and the Central Office of Information (1982); Hoot (1971); Lamb (1967); Lawrence Radiation Laboratory (1961); Leland (1958); Longinow and Stepanek (1968); Mason and Schroeder (1953); Office of Civil Defense (no date, August 1962b, August 1962c, August 1962d); Ormerod (1983); Oster (1985b); Ostrowski (1962); Ralph M. Parson, Company (1968);Rush (1965); Sartor, LaRiviere, Lee, and Pond (1963); Sawyer (1969, 1985); Sibley (October 1981, November 1981, December 1981, March/April 1984, September/October 1984, November/December 1985); Ward (1982, 1983, 1984).

7.6.1 Swiss Basement Shelters

Switzerland has the most highly developed civil defense program in the world; the same is true of their shelter technology. Reliability and protection are their first considerations; cost is a secondary concern. The cost per Swiss shelter space has been estimated at between $350 and $500 U.S. dollars (Federal Office of Civil Defense, 1983, 1985; Heinzmann, 1985). These costs include well-engineered ventilation systems, blast doors, blast valves, and escapeways.

A comprehensive description of the standard design for Swiss shelters is available in Cristy (1973a). The Swiss concept is to construct a reinforced concrete shelter in the basement of every new building; the shelter must contain enough space for the estimated population of the building. Two standard sets of designs are included, one for one-atmosphere (14.7-psi) and one for 3-atmosphere (44.1-psi) shelters. These pressures are static rather than dynamic overpressures, but give an adequate estimate of the ultimate strength of the shelters.

The Swiss have recognized that rubble and fire pose problems in the use of basement shelters. In a basement which might be filled with burning debris, there could be two walls of the shelter exposed to the fire. To deal with the fire problem they specify a 12-in. thickness for concrete walls exposed to the basement area in buildings which have one frame story aboveground. In buildings with two or more wood frame stories aboveground, they specify a 16-in. thickness for walls and roof which could be exposed to the fire.

Recognizing that rubble can block the basement shelter access door, they require a minimum of one external escape shaft for the smallest shelter--less than 13 spaces. For shelters of 50 spaces or more, an escape tunnel, extending out at least one-half the building height, is specified in addition to escape doors. This length can be shortened if it connects to escape tunnels from other shelters.

Initial nuclear radiation is a hazard recognized by the Swiss authorities but the provision for shielding in these 1966 instructions apparently envisions very large nuclear weapons which present a much less serious initial nuclear radiation threat. For example, a 22-in. thickness of concrete is specified for the roof of a basement shelter designed for three-atmospheres (44.1-psi) overpressure. This thickness is marginal for the initial nuclear radiation from megaton yields and inadequate for 100-kT yield explosions.

Figure 7.17 is a representative example of a one-atmosphere (14.7-psi), small Swiss basement shelter for a maximum of 25 occupants. An escape shaft to the outside is specified in addition to the access door from the interior of the basement. One shelter wall is shown partly exposed aboveground with the ground level coming within about two feet of the ceiling of the shelter. The thickness of that wall is specified as 50 centimeters, or 20 inches. The walls exposed to the basement interior are specified as 35 centimeters, or 14 inches.

The reinforcing steel schedule is specified in metric units. The number following the symbol "ø" is the reinforcing bar diameter in millimeters; the number following the letter "a" is the bar spacing in centimeters. Most of the steel bars in this Swiss design are 10 millimeters in diameter, which is about 5% larger than the U.S. No. 3 reinforcing bar (3/8-in.-diam). All the bars have 6-in. spacing both ways, except at the exterior faces of the roof and within the buried wall where the spacing is 12 inches. The design depends critically on the outer bars in the walls being bent over and into the top layers of the roof. The roof then acts like a fixed slab rather than a simply supported slab with a factor of 3 reduction in bending moment at the center. It is a very economical design.

The blast door is not shown in Fig. 7.17. Reinforcing around the entry opening is shown to take the load of the hinges and latches of the blast door. Additional reinforcement has been added in the slab above the entryway to cantilever this portion in hopes of preventing rubble from blocking the cellar door.

As mentioned earlier, this design is for 1-atmosphere (14.7-psi) static pressure. If this shelter is analyzed by yield line theory (see Section 4.1.1), which assumes the steel is stressed well into its plastic region,peak shock loads about 30% greater than the static load can be sustained (Denton, 1967). If credit is taken for two-way slab action as well as fixed edges of the roof, the strength of the shelter is about 22 psi.

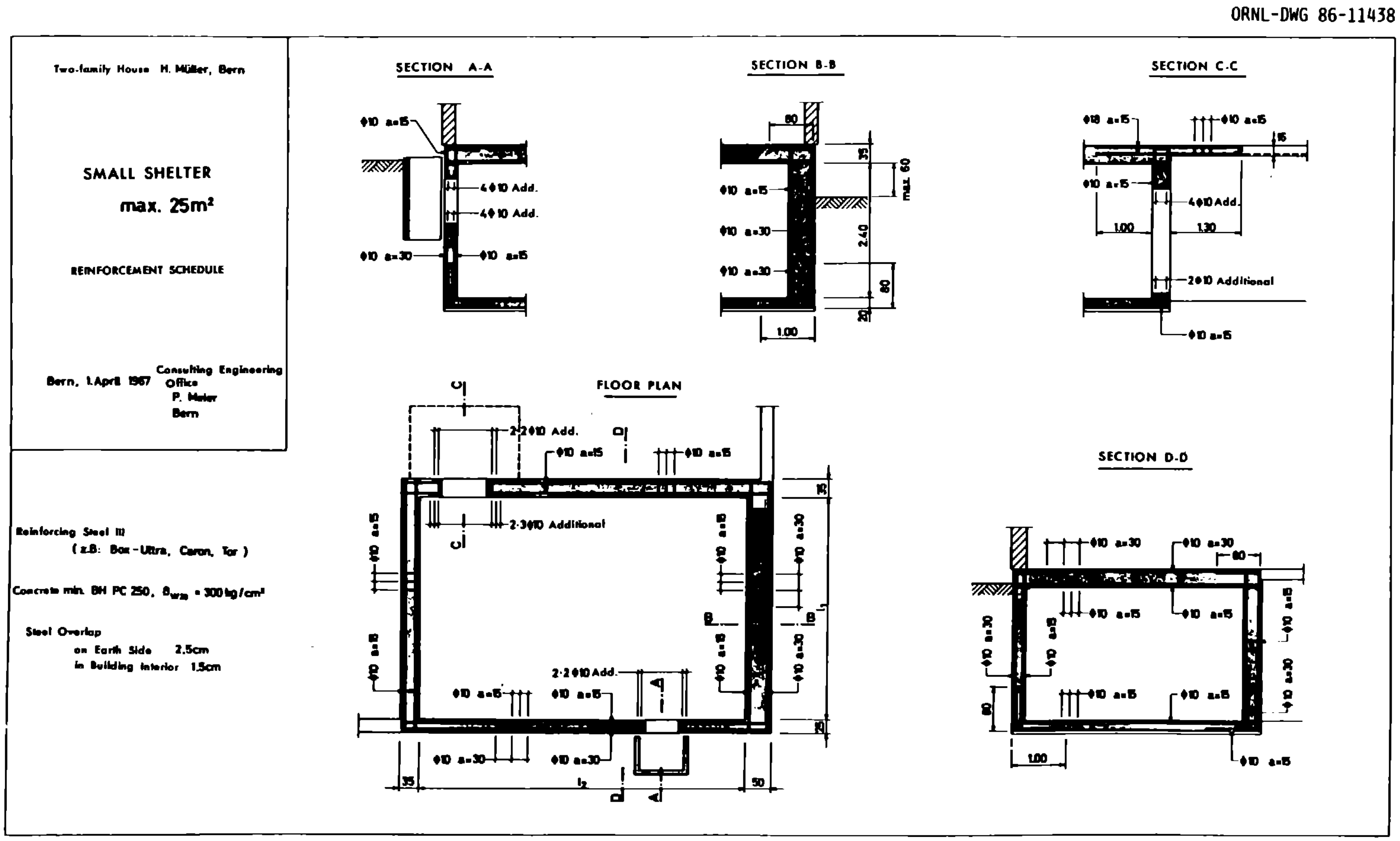


Fig. 7.17. Swiss small shelter.

7.6.2 Retrofit Family Shelters

There has been considerable interest over the years in family shelters which can be added to existing homes either in the basement or buried in the yard with or without connection to the basement. Retrofit family shelters can include shelters that provide only fallout protection as well as those that provide both fallout and blast protection.

7.6.2.1 Family Fallout Shelters

The U.S. Federal Emergency Management Agency (FEMA) and its predecessors have produced pamphlets with instructions on the construction of residential fallout protection.

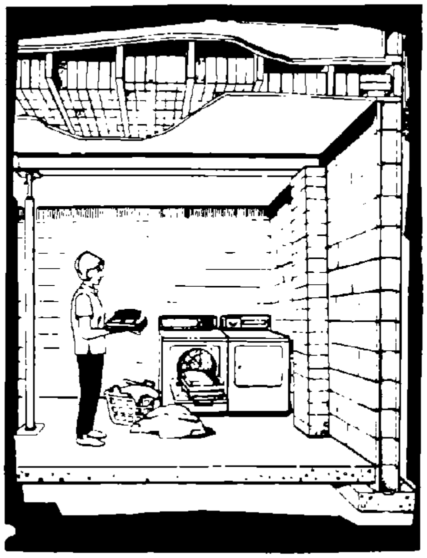
Figure 7.18 is the cover illustration of FEMA Publication H-12-A, which includes the plans for installing concrete block in a basement ceiling to improve fallout protection in the corner of the basement (Federal Emergency Management Agency, 1980a). Figure 7.19 is the illustrative cover of FEMA Publication H-12-C, a "stoop-in" concrete block basement corner shelter (Federal Emergency Management Agency, 1980c). These shelters provide a fallout protection factor better than 40. They have the disadvantages of being in a basement vulnerable to possible fire if a large weapon explodes within 20 miles, and of not being provided with forced ventilation capable of maintaining endurable temperatures in hot weather.

Figure 7.20 is the illustrative cover of FEMA Publication H-12-1, the "Belowground Home Fallout Shelter" (Federal Emergency Management Agency,1983a). This shelter is an 8-ft by 12-ft concrete box placed under a patio or under two or three feet of earth cover. Under the patio it has a protection factor on the order of 1000; this is much higher with the additional earth cover. A prototype of this shelter was tested in an actual nuclear weapons explosion (Roembke, 1958b). It was subjected to 13 psi from a small-yield device without detectable damage.

For areas with a high water table, FEMA Publication H-12-2 provides the plans for an aboveground home fallout shelter which is detached from the dwelling, see Fig. 7.21 (Federal Emergency Management Agency, 1983b). It is a thick-walled tool shed with a labyrinth entrance. It probably provides a fallout protection factor in excess of 100.

Figure 7.22 is an example of a backyard, fiberglass shelter which is currently offered for sale in the United States; the Homestead Company sells a series of three such shelters. These shelters have been primarily marketed as storm cellars, but they would also provide some minimal amount of protection against

ORNL-DWG 86-11130



Protection is provided
in a basement corner
by bricks
or concrete blocks
between the overhead joists.
A beam
and jack column
support the extra weight.

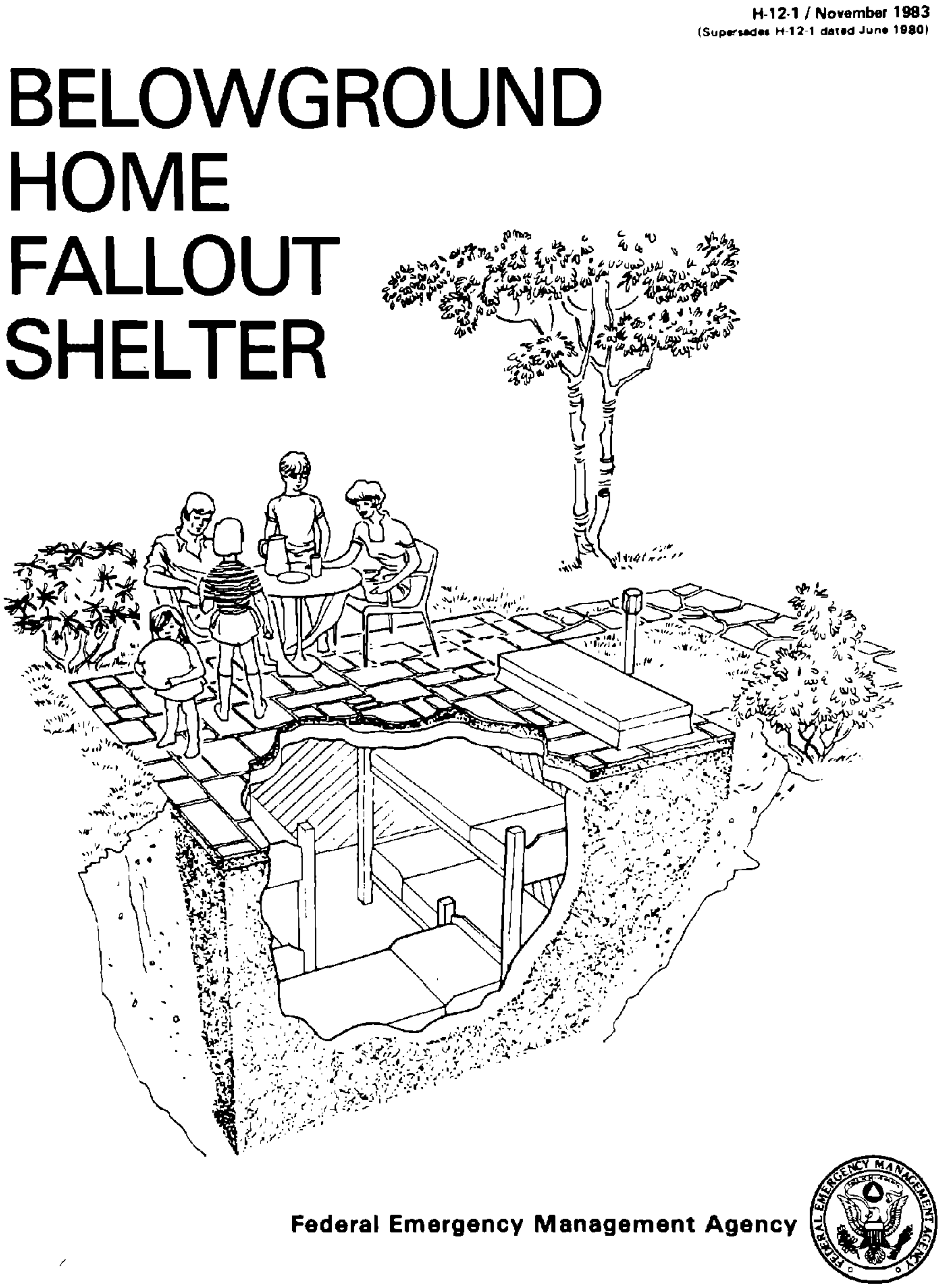
Fig. 7.18. Home fallout shelter--modified ceiling design, basement shelter.

ORNL-DWG 86-11131

A compact shelter
is provided
in a basement corner
by the use of
common lumber
and concrete blocks
with mortar joints
for permanent construction.

Fig. 7.19. Home fallout shelter--concrete block design, basement location.

ORNL-DWG 86-11132



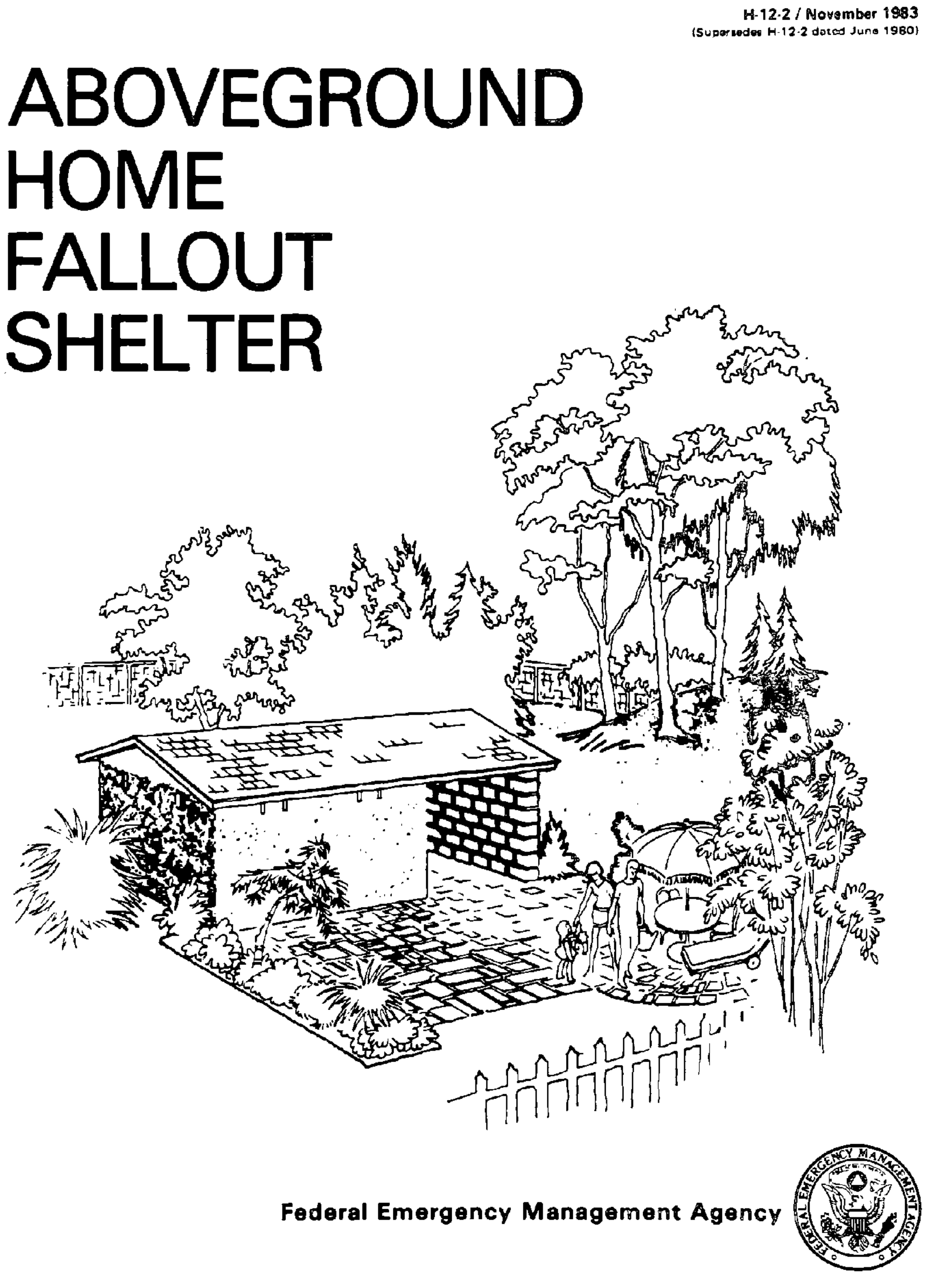
H-12-1 / November 1983
(Supersedes H-12-1 dated June 1980)

BELOWGROUND
HOME
FALLOUT
SHELTER

Federal Emergency Management Agency

Fig. 7.20. Belowground home fallout shelter.

ORNL-DWG 86-11133



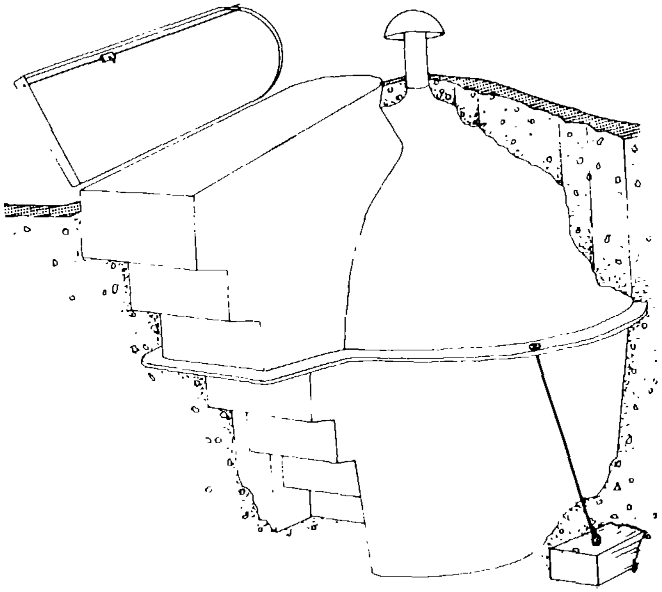
H-12-2 / November 1983
(Supersedes H-12-2 dated June 1980)

ABOVEGROUND
HOME
FALLOUT
SHELTER

Federal Emergency Management Agency

Fig. 7.21. Aboveground home fallout shelter.

ORNL-DWG 86-11128



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Additional Information Available from:

THE HOMESTEAD COMPANY
Box 86
Deerfield, MO 64741
phone: (417) 966-7322

Fig. 7.22. HOMESTEAD COMPANY storm cellar shelter.

fallout. The three cellar-shelters range in price from $1600 to $2900; they all have an advertised capacity of ten persons, although such a large number of occupants could not remain in the shelter for long periods of time.

7.6.2.2 Family Blast Shelters

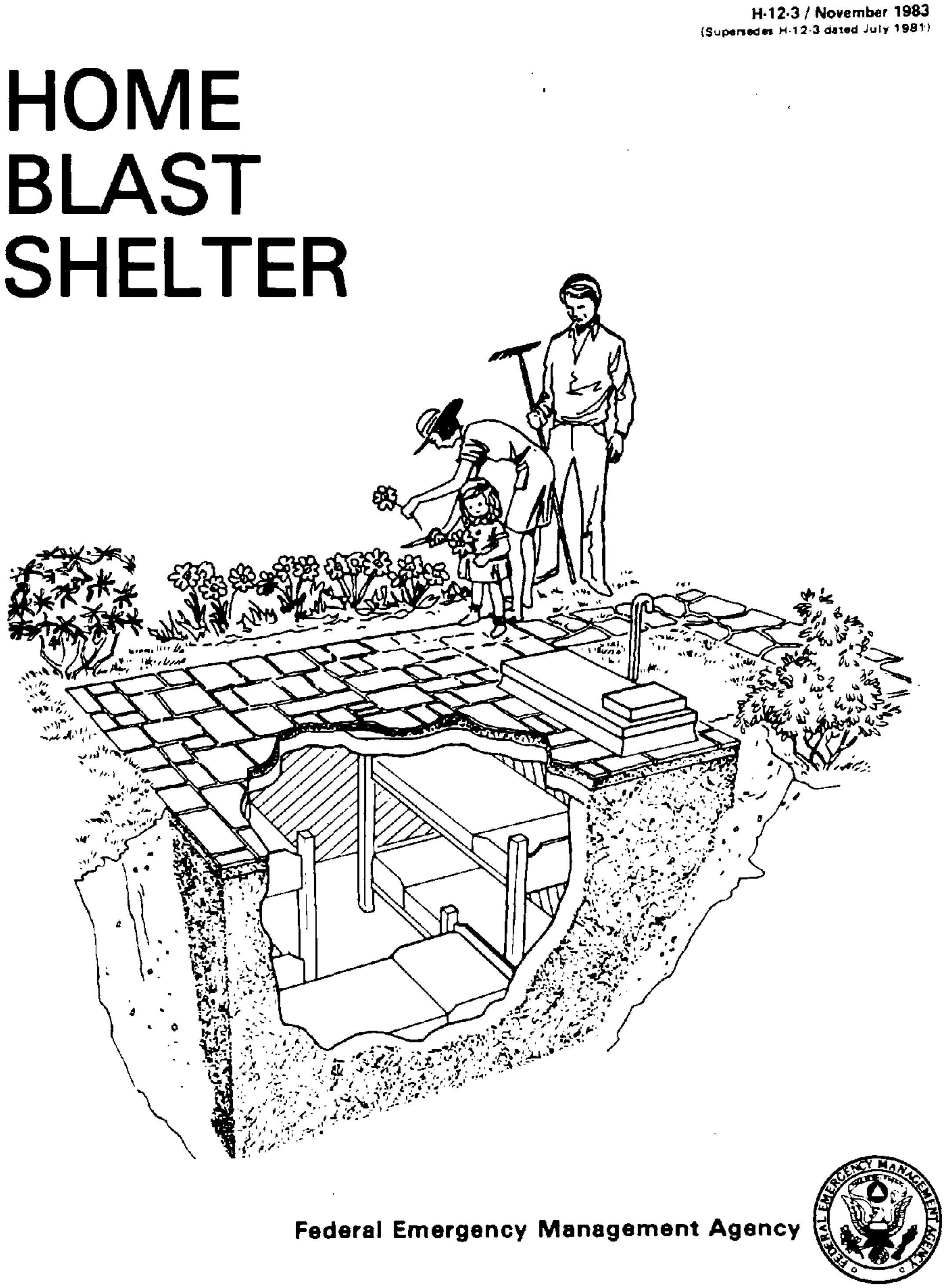
FEMA, its predecessors, and the Canadian Emergency Measures Office (EMO) have developed a number of blast shelter designs for construction under or on suburban yards. FEMA's patio blast shelter, see Figs. 7.23a, 7.23b, and 7.23c, can be constructed in an existing yard and is advertised as providing one atmosphere blast protection; a fallout protection factor approaching 1000 can be obtained when this shelter is constructed flush with grade (Federal Emergency Management Agency, 1983c). This shelter is an 8-ft by 12-ft concrete box with a vertical entryway covered by a wooden hatch of sufficient strength to resist the blast. Ventilation is accomplished by a hand-cranked blower connected to a 4-in.-diam air intake and exhaust. Furnishings, sanitation, food, and water storage are not specified.

This shelter is an interesting contrast to the Swiss basement blast shelter since they are both advertised as resisting the same overpressure (15 psi), and they both have the same roof thickness --about 13-1/2 inches. The FEMA shelter has an 8-ft minimum roof span, and the Swiss shelter has a 13-ft span. The FEMA shelter calls for 0.5% reinforcing steel in the roof slab, and the Swiss shelter calls for 0.16% steel in the roof. On the face of it, the FEMA shelter should be about six times stronger than the Swiss shelter. This is in fact the case; analyzed by yield-line theory, it should withstand 200 psi. It is designed very conservatively to remain within the elastic range of the structure and not to crack under the design load.

In the FEMA shelter no credit was taken for two-way action in the roof slab. The roof is designed as a pne-way slab. It was designed to resist 30 psi in order to remain within its elastic range at under a 15-psi shock loading. There is one important advantage to this conservative, one-way roof slab design: additional lengths of shelter (which use the same roof reinforcement schedule) can be constructed with no loss of design shelter strength. This is not true for the two-way roof design of the Swiss shelter, which specifically matches the size of the roof slab with the desired design strength; each different size of Swiss shelter should have a different roof slab design.

If designed as a fixed-edge, two-way slab by yield line theory, (see Section 4.1.1), then 80% of the steel on the FEMA shelter could be eliminated without compromising its advertised 15-psi blast resistance. However, if exposed to a 15 psi blast, the redesigned slab would crack and subsequently would most likely

ORNL-DWG 86-11134



H-12-3 / November 1983
(Supersedes H-12-3 dated July 1981)

HOME
BLAST
SHELTER

Federal Emergency Management Agency

Fig. 7.23a. FEMA home blast shelter.

ORNL-DWG 86-11135

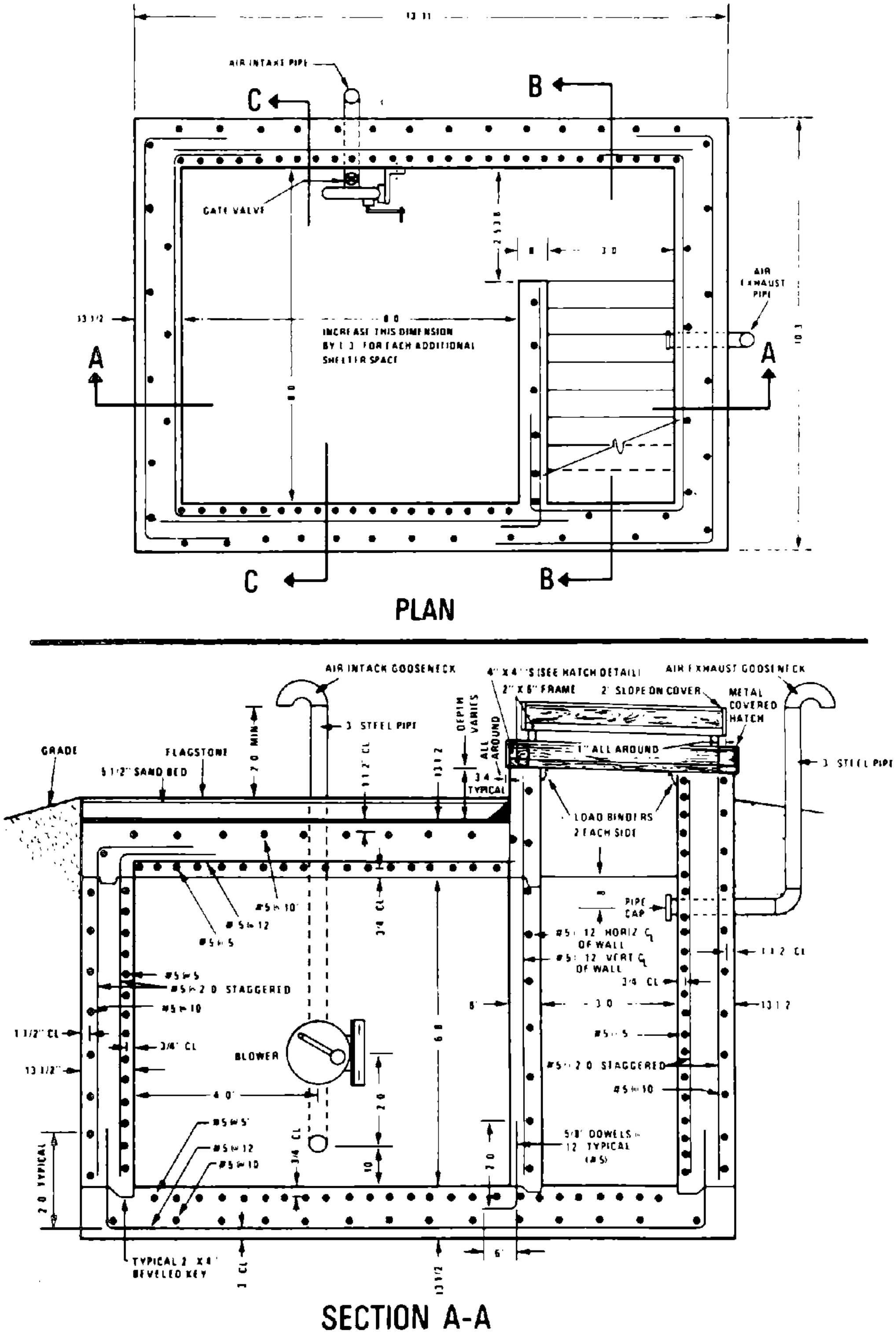


Fig. 7.23b. FEMA home blast shelter.

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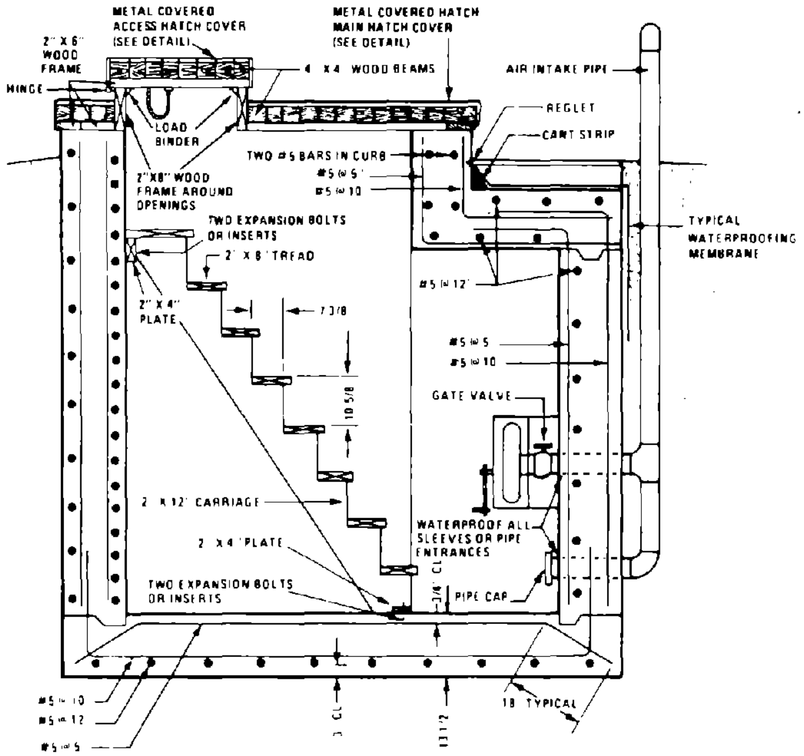
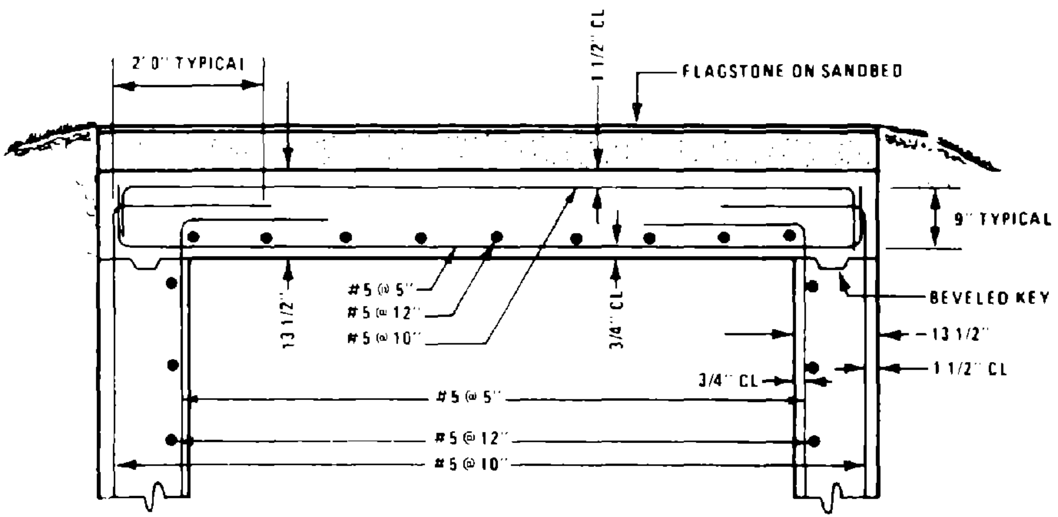


SECTION B-B



SECTION C-C

Fig. 7.23c. FEMA home blast shelter.

leak during rainstorms, particularly when installed at grade levels. These leaks could carry radioactive fallout inside the shelter.

While the FEMA shelter provides a protection factor of 1000 against fallout at grade level, if the shelter were subjected to an intermediate-yield explosion, it would be exposed to high levels of initial nuclear radiation. Its protection factor against this radiation from a low-altitude airburst is only in the neighborhood of 50 (See Section 4.2). This is marginal against an intermediate-yield threat.

The Emergency Measures Organization (EMO) of Canada (1962a) has published plans and specifications for 30-psi family blast shelters (see Figs. 7.24a and 7.24b). This is generally a good design which does attempt to fix the edges of the roof slab to the walls. It has even more steel than the FEMA shelter and hence has an ultimate strength much greater than 200 psi with the recommended 2 ft of earth on the roof. The weak point on this shelter may be the blast door which is claimed to be good for slightly more than 30 psi.

An attempted improvement on the FEMA shelter is the "wine cellar/root cellar/tornado shelter" (Fig. 7.25) described by Chester and Holladay (1983). This shelter design incorporates an attempt to use earth arching to obtain overpressure resistance of 3 atmospheres (44.1 psi), provide protection against initial nuclear radiation, and at the same time offer some peacetime uses due to improved access. It is classified here as a single-purpose shelter rather than dual-use, since the dual-uses cannot be considered economic necessities.

Connecting this shelter to an existing basement will make its peacetime uses much more convenient. With the skylight it should have a much more pleasant atmosphere. Connection to the basement, although increasing the cost of the shelter substantially, would make possible a safer, more rapid access in an emergency--either an approaching tornado or a warning of imminent nuclear attack. The cost of this 8-ft by 12-ft shelter was estimated at close to $10,000 in 1983.

7.6.2.3 Corrugated Metal Blast Shelters

Arch or pipe shelters constructed from corrugated metal sheets have been demonstrated to have remarkably high blast-resistance when covered with at least half a span or diameter, or more, of a granular soil (see Sections 4.1.2 and 5.1). DONN Products (Brown, 1978; Petras et al., 1979a, 1979b) developed and tested a version of their corrugated metal shelter (Fig. 7.26) which they believe could be sold for around $200 per space. Chester and Holladay (1983) slightly modified the DONN design to

ORNL-DWG 86-11141

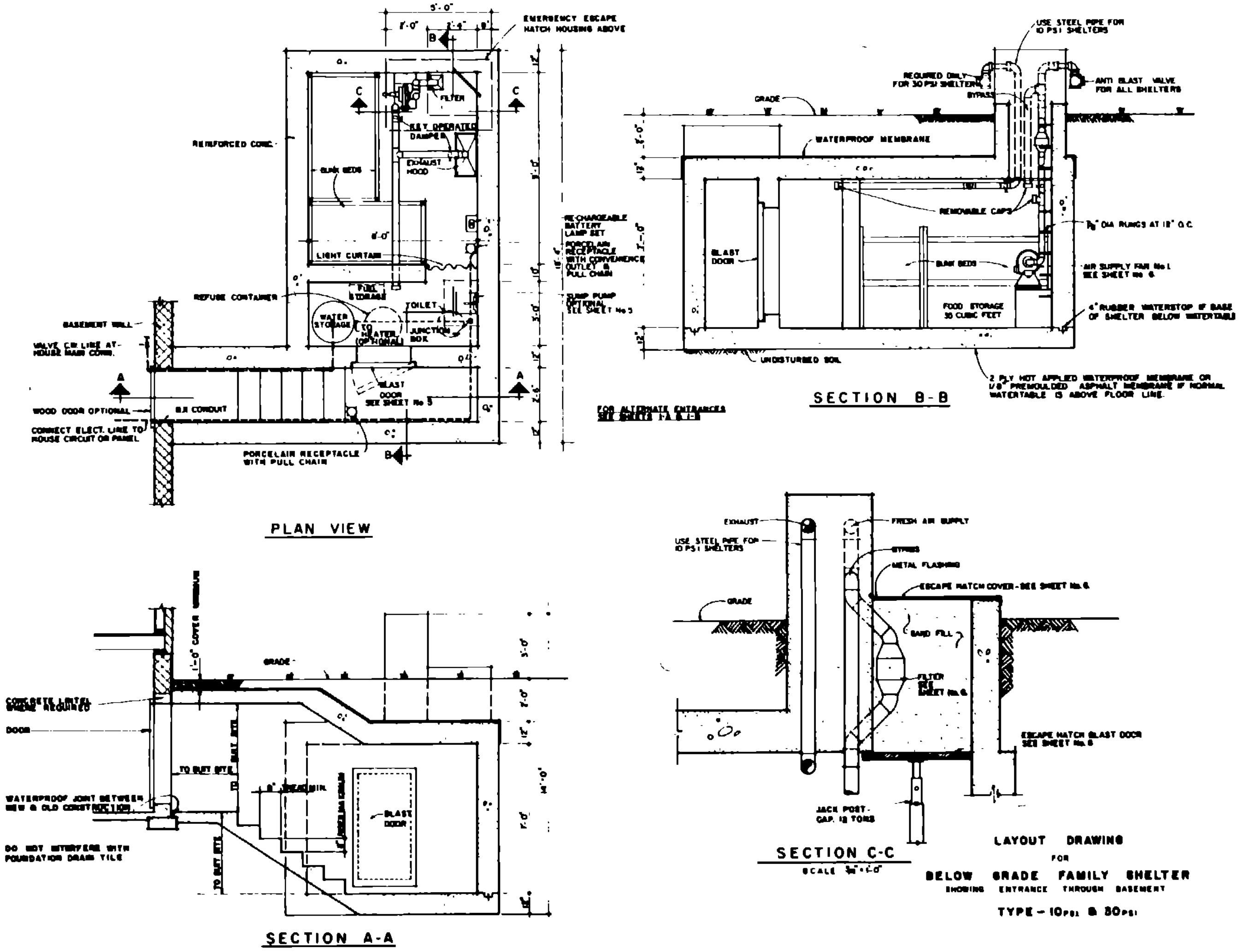


Fig. 7.24a. Canadian EMO blast shelter.

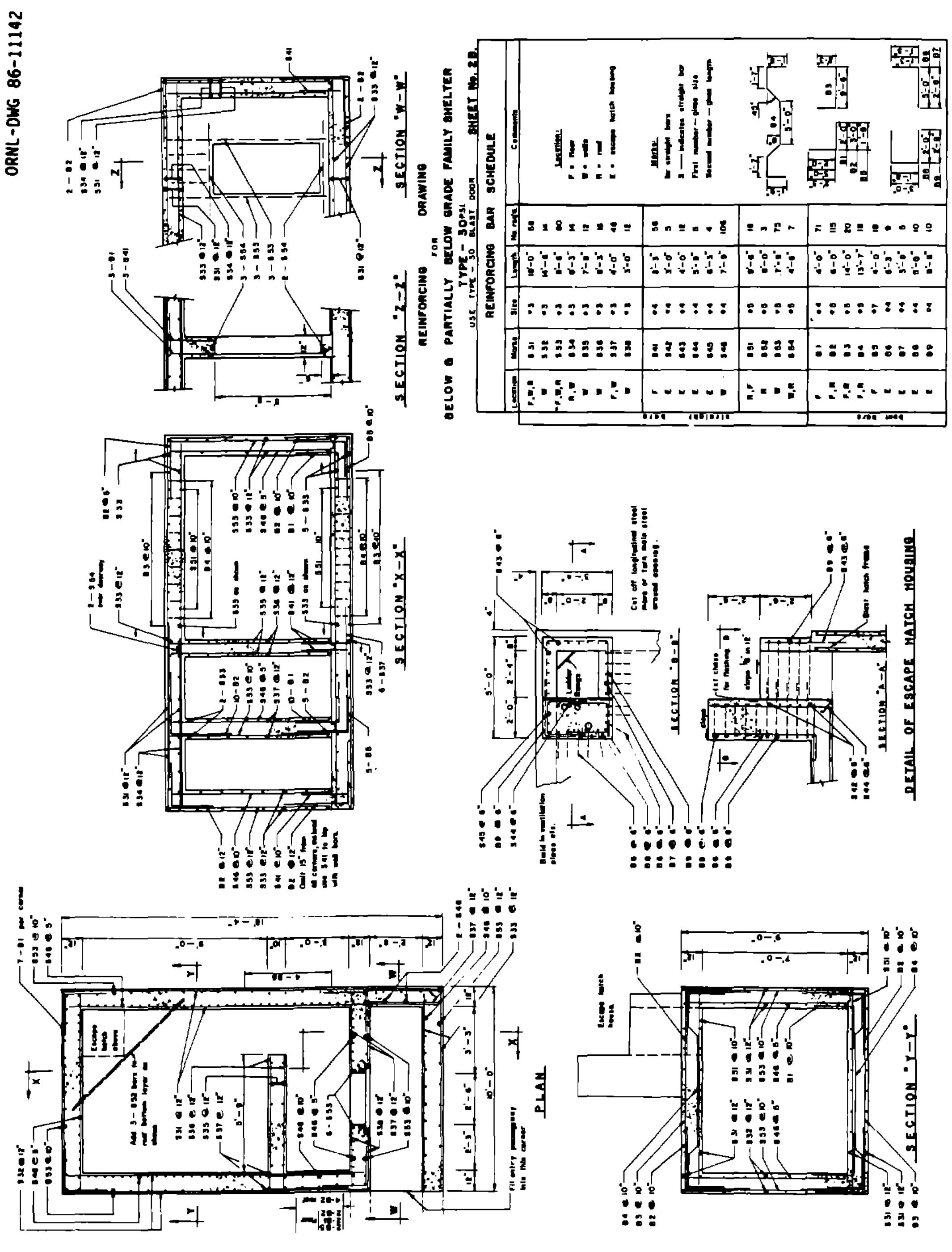


Fig. 7.24b. Canadian EMO blast shelter.

ORNL-DWG 83-13445

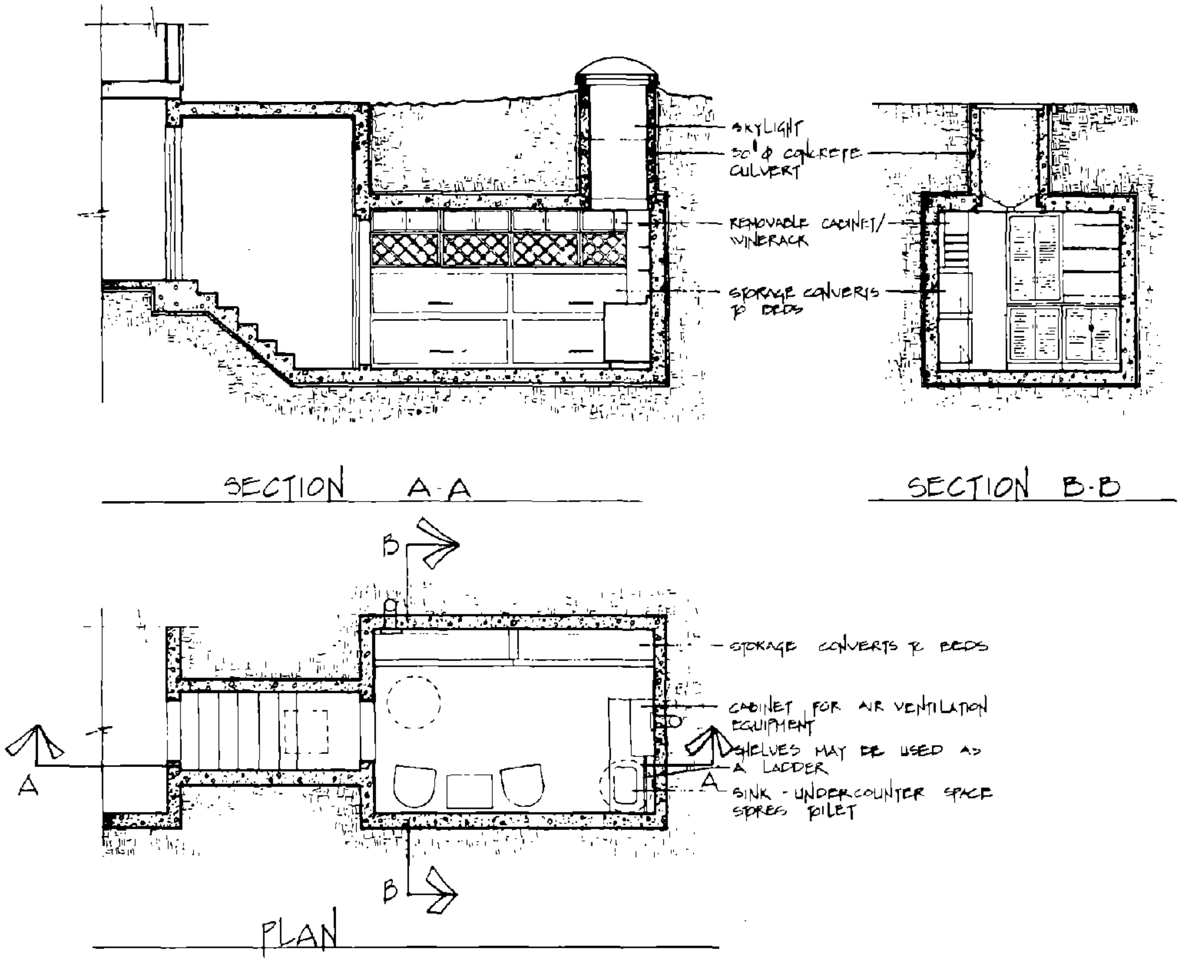


Fig. 7.25. Wine/root cellar shelter.

ORNL-DWG 86-10191

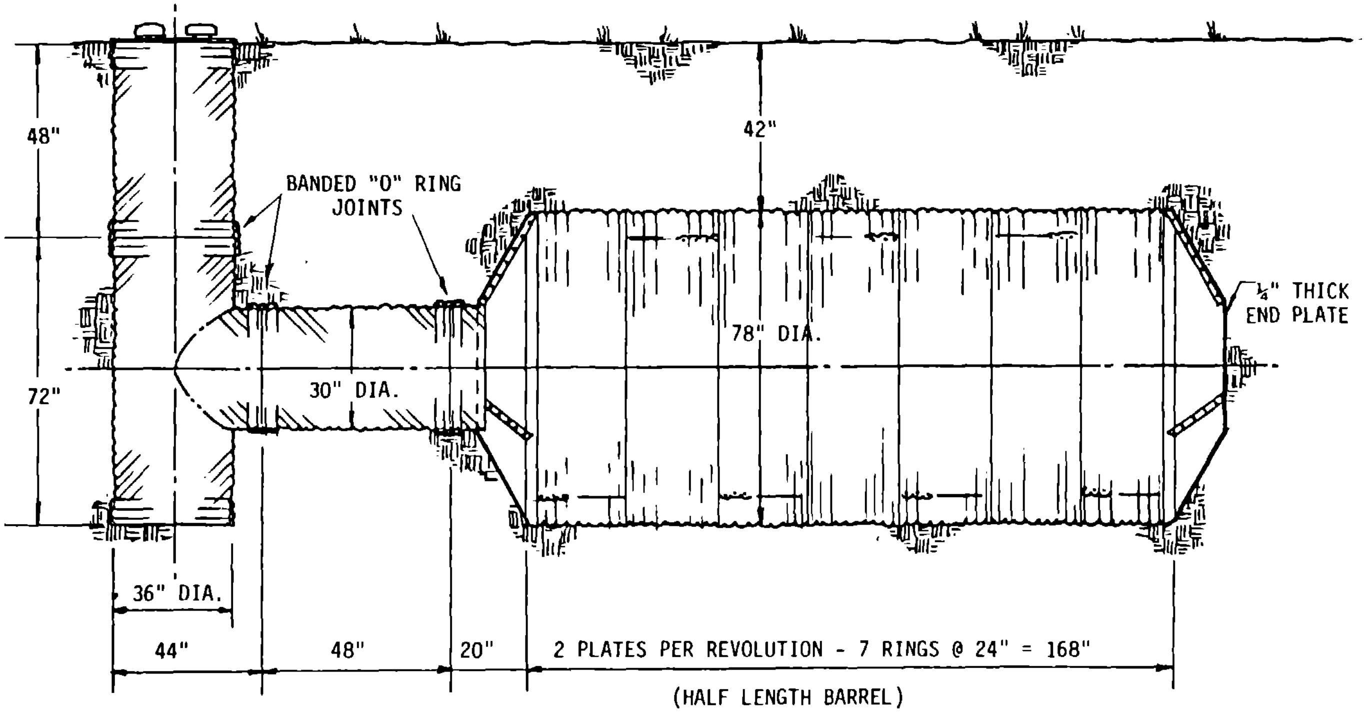


Fig. 7.26. DONN Products corrugated metal blast shelter.

make access more convenient and incorporated some habitability equipment, ventilation, and water storage (Fig. 7.27). They estimated the cost per space to be in the neighborhood of $500. A 1/4-scale model of this shelter was tested successfully at 50, 100, and 200 psi in an actual high-explosive field test (Zimmerman and Chester, 1984). The U.S. Army Corps of Engineers actually constructed and successfully tested a full-sized, somewhat over-designed, variant of this shelter which cost about $2000 per space (Woodson, Slawson, and Holmes, 1986). It is believed that the price could be reduced to $1000 per space in quantity production.

A luxurious version of a corrugated metal blast shelter is being offered for sale in the United States by Survival Products, Inc. (Fig. 7.28). This shelter, which is rectangular with an arched roof and flat ends, will accommodate 6 people in relative luxury. A cost of $20,000 is quoted for a completely assembled shelter. A kit to be assembled by the purchaser is offered for $5000 without any habitability equipment. The cost approaching $4000 per space is characteristic of luxurious shelters for small groups of people. While it may be of interest to a few wealthy individuals, it cannot be considered a basis for a serious national shelter program without some strenuous cost engineering.

7.6.3 Retrofit Critical Worker Shelters

In any serious civil defense program whether it involves shelter-in-place or evacuation, certain activities in very high risk areas will have to be maintained. These activities can include logistic support for U.S. military forces, maintenance of vital services for the civilian population (such as food and electric power) and maintaining vital economic functions. High quality shelter will have to be provided for the people (critical workers) who carry out these necessary functions in risk areas. Shelters must be located near their place of employment so that they can get to shelter in the anticipated warning time, which could be very short.

Design overpressure for this type of shelter is currently specified as 50 psi by FEMA. The rationale is that, above this overpressure, ground motion (with its consequent expense in shock isolation) becomes a problem. This is also the approximate blast overpressure on the ground directly underneath an airburst which occurs at the altitude necessary to optimize the area coverage of 20 psi, a typical overpressure intended to destroy industry.

These shelters would of necessity be constructed for relatively small numbers of people, perhaps 20 to 100 persons at any given location and in general would be constructed at existing vital facilities. Three general categories of design exist: (1) rectangular concrete construction, (2) concrete or corrugated

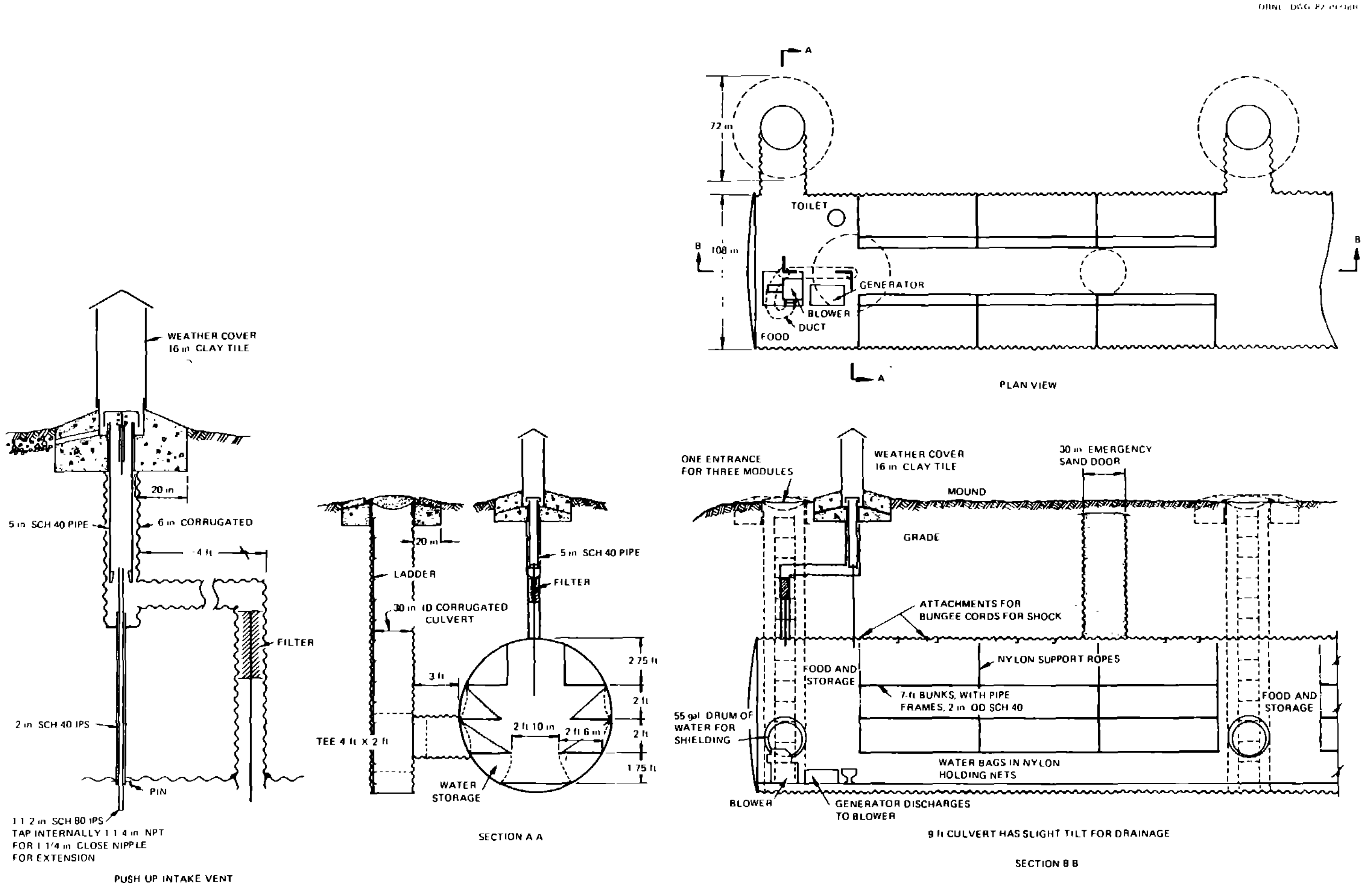
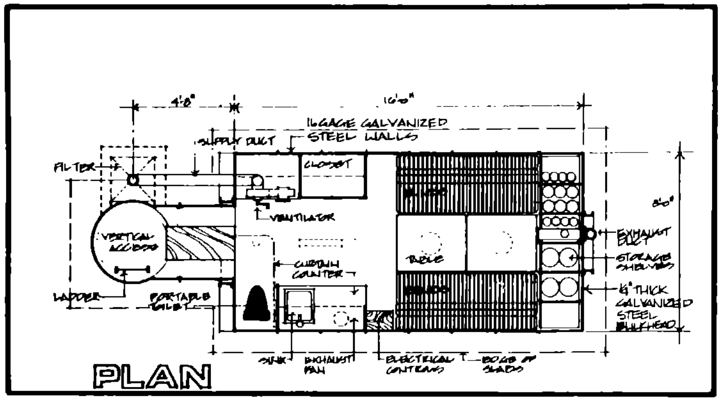


Fig. 7.27. ORNL corrugated metal blast shelter.

ORNL-DWG 86-10190



SURVIVAL AND RECREATIONAL SHELTER

A Complete Information Package
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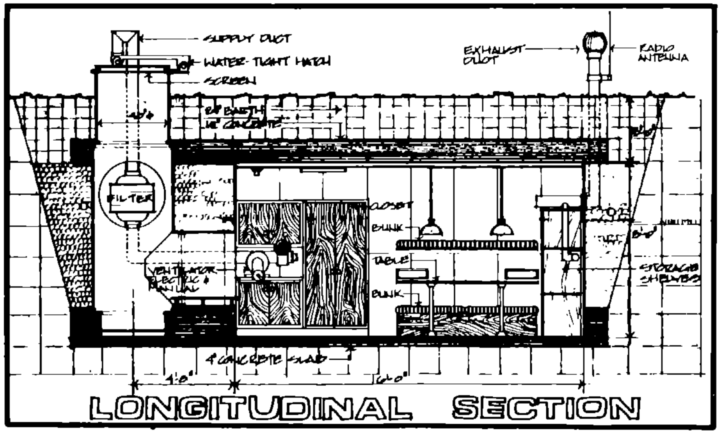
THE SURVIVAL CENTER
5555 Newton Falls Road
Ravenna, OH 44266
phone: (216) 678-4000



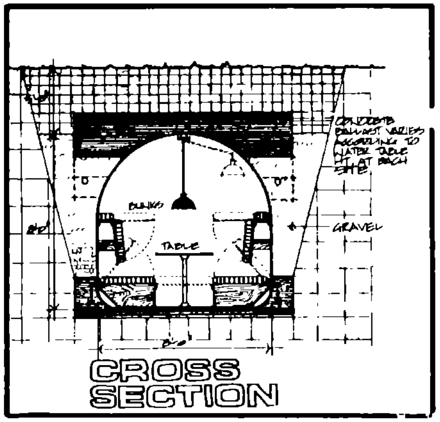


Fig. 7.28. Survival Products blast shelter.

metal hemicylindrical arches of 12-ft radius, or (3) concrete or corrugated metal pipes 8 ft or more in diameter. Installation would be by cut and cover in open areas or parking lots near the facilities which must be kept operating. Figure 7.29 is a drawing of a design of a corrugated metal arch shelter (Porteous, 1962; Strope, Porteous, and Greig, 1959). Figure 7.30 shows a corrugated culvert version of a critical worker shelter. A concrete box shelter,see Fig. 7.31, was designed by the U.S. Army Corps of Engineers (Kiger and Slawson, 1977) and constructed in Fort Worth, Texas. The cost per space was approximately $2500 for this one-of-a-kind first attempt. It is expected that the price would drop significantly in serial production, possibly toward $1000 per space.

7.6.4 Dedicated Tunnel Systems

In studies of shelter within central cities, it has been recognized that the production of rubble and large fires complicate the designs of escape routes and ventilation of shelters underneath buildings. An obvious solution used by the Swiss, among others, is to connect shelters to lengthy, interconnected escape tunnels. It was discovered that for most urban population densities, these escape tunnels, if made 8 ft in diameter, provide enough area and volume for the population without the necessity for shelters under the buildings (University of Arizona, June 1964; Holmes and Narver, 1965).

In the United States the concept of a connected tunnel shelter system for civilians has never gotten beyond the conceptual design stage. In contrast, the People's Republic of China has constructed extensive tunnel networks underneath all of its population centers for protection of the civilian population against both blast and fallout from a nuclear attack. Tunnels are constructed at depths from 10 to 100 ft. with access points throughout the cities. Construction generally employs concrete or masonry arches (National Civil Defense Guidance Group Office, 1981; Wukasch, 1982). The underground systems include connecting tunnels at least 4.5 ft wide by 7 to 9 ft high, larger tunnel--shelters about 25 ft in width, and side rooms of varying sizes. They are equipped with electrical illumination, piped-in water, and ventilation. The tunnels were constructed initially for protection of the civilians and as fortifications, permitting movement of the military in the face of enemy occupation. As construction has continued, most of the larger spaces have been used for compatible peacetime purposes such as restaurants, industrial manufacturing, or recreation areas. New complexes of blast-protected rooms have been added for use as peacetime hospitals, capable of sheltering many more people in a crisis.

The cost for a comparable government-financed system would be prohibitive in the United States. The Chinese apparently carried

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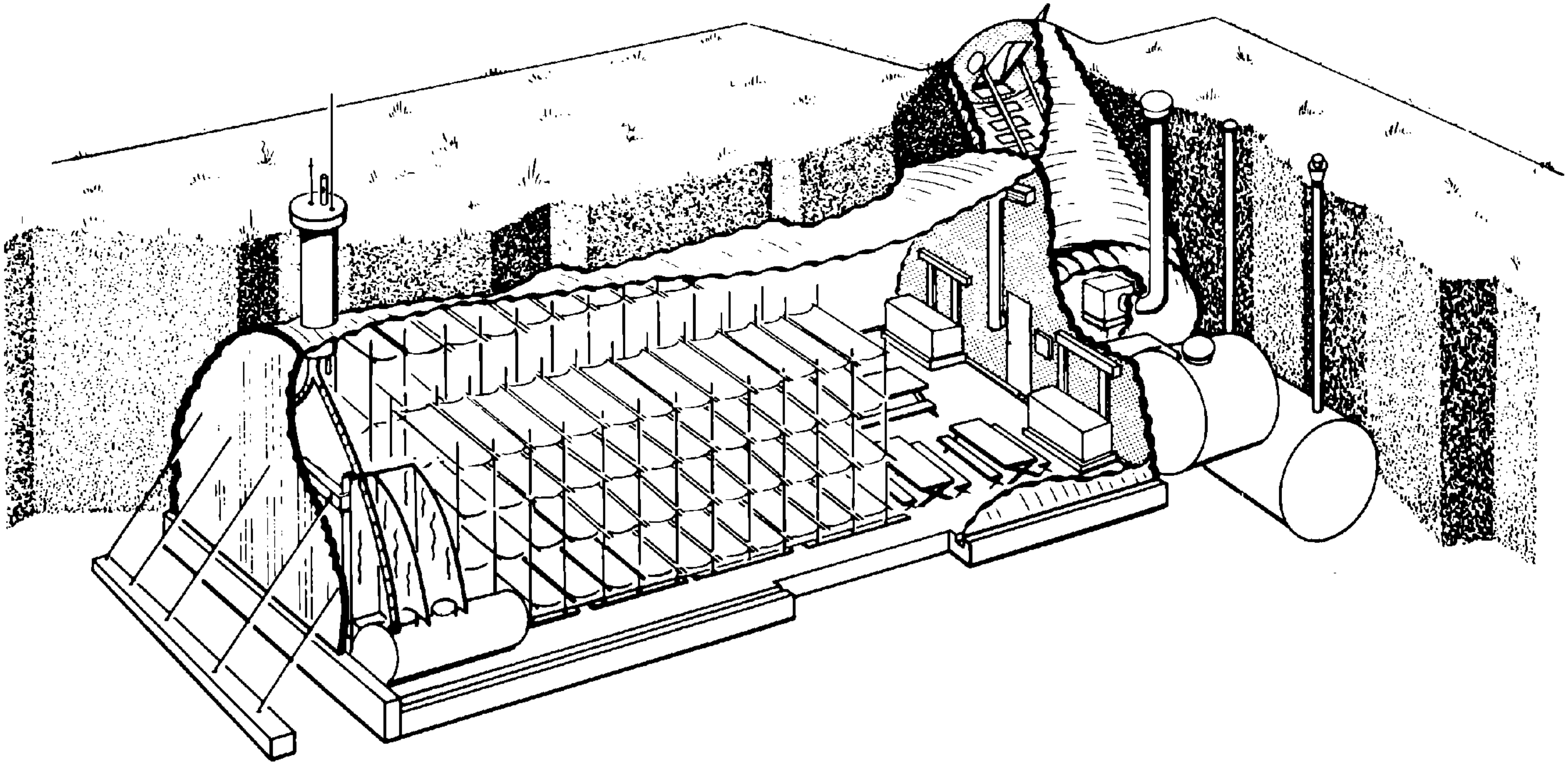

Fig. 7.29. Corrugated metal arch shelter.

(SOURCE: U.S. Army Corps of Engineers, Huntsville Division.)

ORNL-DWG 86-14302

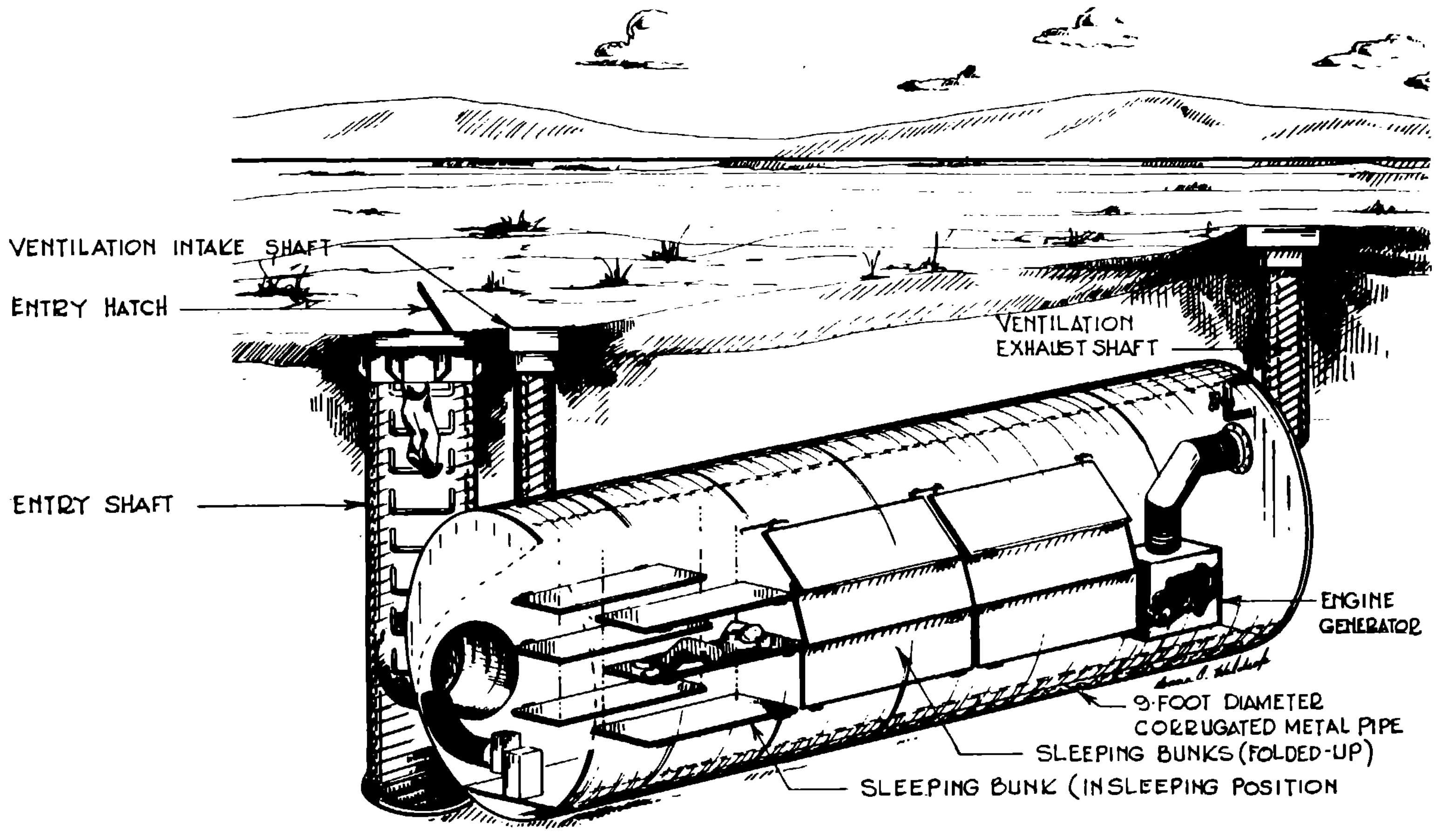

Fig. 7.30. Corrugated metal blast shelter for keyworkers.

(SOURCE: U.S. Army Corps of Engineers, Huntsville Division.)

ORNL-DWG 86-14301

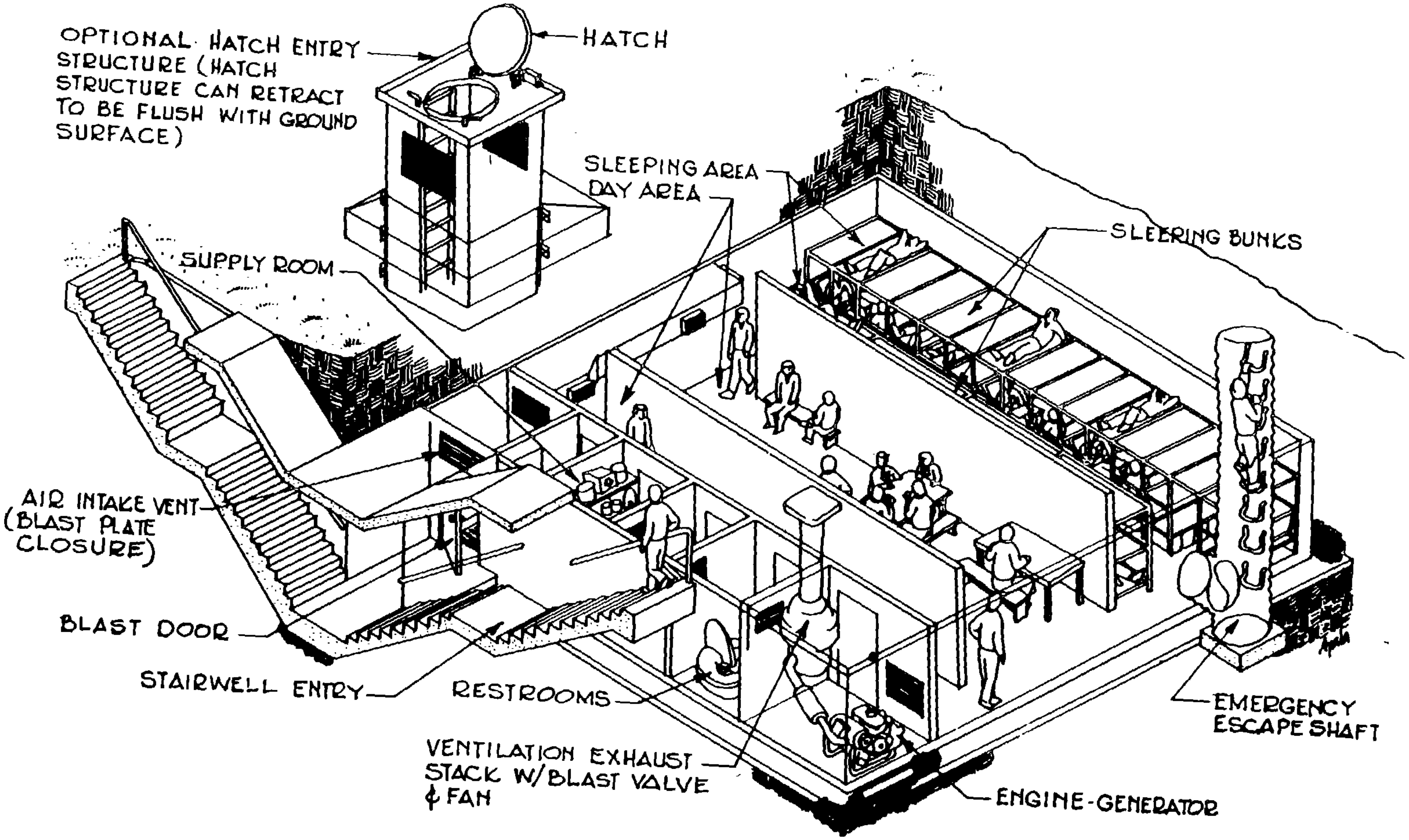

Fig. 7.31. Belowground, reinforced concrete blast shelter for key workers.

out the construction of their tunnel system with little or no impact on their economy. One reason why this was possible is that the cities of China are not underlain with the complexity of utilities which are found beneath U.S. cities. Most importantly, the tunnels were constructed from indigenously produced brick and masonry units and required remarkably little steel reinforcement. Both the production of the building materials and the digging and construction of the tunnels were performed mostly by "volunteer" labor working after normal working hours and on weekends. When these tunnels were started in 1968, China was in great fear of a preemptive Soviet nuclear attack intended to destroy Chinese nuclear capability and possibly leading to the Soviet occupation of the industrial areas in Manchuria. The anxiety levels must have been much higher than they were in the United States in the summer of 1961.

For additional information on dedicated tunnel shelters, the following references are suggested: Barnett (1958); Baschiere, Humphreys, McKee, and Vey (1958); Coulter (1966); DeLeuw, Cather and Company (1963); Hibbard et al. (1971); Kriebel (1972); Lamoureur (1967); Newman (1966); Scott and Holmes (1965); U.S. Army Corp of Engineers (January 1961, April 1961); University of Arizona (1965).

8. CONCLUSIONS

8.1 SUMMARY

This report is a comprehensive review of what is known about shelter from the available literature in the United States. An attempt has been made to concentrate on the information which should be known by a U.S. planner. Shelter against a number of natural and technological hazards is considered, but the most important threat and the one about which the most information exists is shelter against nuclear weapons effects.

The most important fact to recognize is that there is a very well developed technology for the protection of civilians against the effects of nuclear weapons. It is potentially very effective and has been extensively tested against real nuclear weapons in the 1950s and, subsequently, blast tested with very large high-explosive charges and shock simulation techniques. Design techniques are covered in a variety of manuals, all of which will produce shelter with very high confidence of effectiveness. However, the reliability of design is usually attained at the cost of great conservatism and excessive expense. The present state of the art in structural design of blast shelters is comprehensively described in Manual No. 42, Design of Structures to Resist Nuclear Weapon Effects (American Society of Civil Engineers, 1985).

Significant savings on the cost of blast-resistant structures can be achieved by making use of the most advanced design techniques, such as "yield-line theory," and making maximum use of improved understanding of soil-structure interactions, such as "earth arching."

The threat to the American public from nuclear weapons is now believed to be of such magnitude that a full shelter program would have to include 160 million blast shelter spaces and approximately 80 million fallout shelter spaces. Blast protection is believed to be required in the areas surrounding military targets and urban-industrial areas. Fallout protection is believed to be required over the entire country.

Existing structures, particularly large masonry or concrete buildings, can provide significant though varying amounts of fallout protection. An effort by the U.S. government to identify such structures in the 1960s and '70s, has identified an inventory of 245 million spaces which can provide protection factors of 40 or more against fallout radiation.

Unfortunately, most of these spaces are in what are presently believed to be risk areas, and many of them are in the upper stories of multistory buildings which are vulnerable to blast effects. The basements of concrete buildings provide some protection against blast effects but only at low overpressures. There is not nearly enough of this "best available" space to protect more than a very small fraction of the risk area population. With today's resources, the only hope of survival of the risk area population in an all-out attack would be a large-scale evacuation of the target areas in several days preceding the attack.

If several hours' or days' warning of an attack are available, highly effective fallout shelter can be improvised. This protection can include improvisation of shelter in the corner of a basement by stacking books, furniture, bags and boxes of earth, and other mass on and around a table in a protected corner of the basement.

In the 1970s, a technology of producing highly effective shelter from tools, materials, and labor at hand was developed. This technique called "expedient shelter" involved the construction of covered foxholes or covered trenches. All these shelters provide fallout protection factors in excess of 100. The designs using unshored trenches will survive blast overpressures in the region of 5 to 7 psi. Lightly shored versions will survive 15 or more psi, and one design has repeatedly survived overpressures in excess of 50 psi. If the information on construction of these shelters could be disseminated to the public and 24 to 48 hours were available for construction, very good protection could be developed for very large numbers of people. For the foreseeable future, it is all they are likely to have.

Far more people would survive a nuclear war if shelter were already in place before the onset of a nuclear crisis. One of the major deterrents to a program providing shelter for all Americans is its cost which will be the product of the cost per space times the number of spaces needed. In the case of blast shelters, the number of spaces needed is approximately 160 million. Fallout shelter spaces needed are approximately 80 million. Small single-purpose small blast shelters can cost from \$500 to \$2500 a space or more, with \$1000 being representative. Blast shelters built into the basements of new construction can be constructed for \$250 to \$500 per space, with \$300 being a good representative number. Fallout shelter built into new masonry construction may cost only in the range of \$50 per space. Slightly altering new construction to make maximum use of features which would have been constructed in any case, such as basements, is called "slanting." This technique is by far the most economical approach to developing shelter.

Construction with the potential for blast slanting includes basements of masonry buildings with concrete first floors; schools and residences designed partially or wholly underground for energy conservation, aesthetics, or tornado protection; and underground mining operations for the production of concrete aggregate or agricultural limestone.

The reader is reminded that shelter is but one link in a whole chain of measures to enable a society to survive and recover from a catastrophe, particularly a nuclear war. The spectacular pyrotechnics of nuclear weapons makes it easy to forget that measures other than shelter are required for the ultimate survival of society. The problems of water supply and food supply for the survivors are only the most immediate of these problems. Equally important in the long run is the reestablishment of food production and production of the vital necessities such as clothing, shelter, and transportation. These will, in turn, require establishment of some type of economy and government authority.

8.2 SHELTER PROGRAM OPTIONS

Table 8.1 very briefly summarizes possible different approaches to production of shelter for the American public, the approximate cost, and major advantages and disadvantages. While the different shelter techniques are presented as options, obviously any real program would have a mixture of shelter techniques, depending on the threat and conditions in the area considered.

For completeness a zero option is included in which nothing is spent for shelter space. Under these circumstances, people would make the best use of available basement or other indoor space in a crisis. With no expenditure even for education or marking of shelters, use of the existing space would be relatively inefficient and the casualties in an all-out attack would be very high, probably greater than 100 million. Of more interest to the political component of our society, the nation would be much more subject to nuclear blackmail under these circumstances. The threat or implied threat of a nuclear attack by the Soviet Union could be very coercive, particularly if the Soviets adopted protective postures for their civilian population (i.e., evacuation of the civilians and sheltering of their critical workers and elites).

Option 1 is described as "best available" shelter. It is Option 0 with the addition of shelter marking and some information and education. This option is effectively the present civil defense program. It could add a small percentage to the survivors of an attack on congested urban areas if the attack were not too massive. It can add significantly to survivors of the fallout outside target areas.

Option 2 is described as crisis upgrading, although it would certainly include the use of space that required no upgrading.

Table 8.1. Shelter options

No.	Option	Cost per space ($)	No. of potential spaces (million)	Advantages	Disadvantages
0	Do nothing	0	--	No cost	Vulnerable to nuclear blackmail; very high casualties
1	"Best available" shelter	1	240	Very low cost	High casualties
2	Crisis upgrading	1-20	240	Very low cost before crisis, low cost during crisis	Requires 1-week warning; use of private proterty; possible cleanup cost; some evacuation required
3	Expedient shelter	1-20	240	Very low cost for planning; low cost during crisis; good protection	One-week warning required; some evacuation required; short life of shelter
4	Fallout shelter in new construction	0-20	240	Low cost	No help for risk area; requires legislation; may require evacuation; long deployment time
5	Mines (modify quarrying near cities	10-100	40-100	Moderate cost; good protection	Not applicable to all cities; 2- to 15-year deployment time
6	Earth-sheltered structures	60-300	160	Moderate cost; 2-yr deployment	Requires legislation, home-sharing, blast upgrading
7	Dual-use basement in new construction	250-750	240	Cost at low end	Rubble & fire in central cities; 5- to 10-yr deployment time; requires some evacuation

Table 8.1. (Continued)

No.	Option	Cost per space ($)	No. of potential spaces (million)	Advantages	Disadvantages
8	Swiss basement shelter in new construction	350-500	240	Good protection; little warning required	Long deployment time; rubble & fire problem
9	Retrofit family shelter	500-2500	240	2-yr deployment; good protection; little warning required	High cost; not applicable in central cities
10	Retrofit dedicated blast shelters (30-50 psi)	1500-2500	200	Good protection; 2 to 5-yr deployment	Very high cost; land requirements in some areas
11	Tunnel shelters under cities	2000-5000	100	Good protection; little warning required; reduced rubble & fire problem; maximum population density	Very high cost; long deployment time

The precrisis investment is listed as \$1 to \$20 per space and would consist principally of local planning efforts. The U.S. civil defense capability has a large component of this option in it at the present time. When coupled with evacuation, this technique is capable of producing space for the entire population for protection against at least fallout radiation.

The principal advantage of this technique is the low precrisis cost. In a sufficiently tense political situation, planning and instructions for crisis upgrading could be developed and disseminated in a few weeks. The principal disadvantage of this technique is that for the target area populations, it has to work in conjunction with an evacuation and thus would require at least a week's strategic warning in order to make maximum effective use of the approach. It utilizes existing buildings with modification in some cases which can include the dumping of large amounts of dirt on the first floor for additional shielding. If war did not occur, there would be a sizable cleanup cost associated with the use of the technique.

Option 3 is described as expedient shelter. This technique employs the construction of the various expedient shelter designs which are available in handbooks (Kearny, 1979). The cost is given as averaging \$10 per space which would be a required investment by the individual families in digging tools and commercially available printed handbooks. The cost to the government would be much less. In conjunction with an evacuation, this technique combined with crisis upgrading of existing buildings has the potential for sheltering the entire population with much better fallout protection than can be attained by crisis upgrading alone. Its advantage is that the cost to the government would be small. The information required could be disseminated in days.

Expedient shelters also have the advantage of providing high levels of protection--in one case, comparable to the best civilian blast shelter designs. Fallout protection factors in excess of 200 are relatively easy to achieve.

The disadvantage of expedient shelter is that it does require several days' strategic warning for the evacuation and construction of the shelter. Expedient shelters, once constructed, would have a finite lifetime in most locations of months to a year or two, although more than adequate for any crisis. The majority of designs include wood structural members which would be greatly weakened by decay and by boring insects in contact with the soil, except in very dry areas.

Option 4 would involve the incorporation of fallout shelter into new construction. The National Fallout Shelter Survey has already located over 245 million shelter spaces in existing construction where adequate protection from fallout is currently available. However, most of these shelter locations lie in potential high-risk areas (in other words, in cities). A "new construction" option would supplement this existing shelter with additional spaces in those areas where shelter is needed the most. Such an option has the potential for providing fallout shelter outside of the risk areas for the entire U.S. population.

Every building contains construction materials which provide some inherent shielding against radiation from fallout. In some of these structures, adequate fallout shelter spaces could be provided at little or no additional construction cost. Buildings with basements appear to fit perfectly into this category. Other structural modifications to new buildings might involve more cost, but 1960s Office of Civil Defense programs have demonstrated that the incremental cost of adding fallout shelter can be small in a large number of cases.

Legislation requiring or providing incentives for fallout shelter in new construction outside risk areas would be controversial. Furthermore, the time to construct sufficient shelter space in those locations where it is needed would be controlled by general construction trends.

Option 5 is to modify concrete aggregate quarrying techniques to produce usable underground space near population centers as is being done in Kansas City and Indianapolis. The cost for space production alone is estimated from $20 to $100 (in 1985 dollars), and it is estimated by Krupka (1965) that up to 100 million spaces could be produced in this manner. Krupka estimated that this space could be developed in 2 to 15 years, depending on the government incentives offered the limestone miners. It is estimated by Wright, Chessin, Reeves, and York (1983) that approximately 35 million spaces could presently be developed in existing mining operations.

The advantage of this approach is cost, which is the lowest for any high-quality permanent protection. The other advantage is the level of protection available--an effectively infinite fallout protection factor and very high blast protection.

The principal disadvantage of this approach is that it is not useful for the entire population. Some areas simply do not have the necessary geological features that are adaptable to the economic mining operations that produce usable space. In most cases, to use such space would require some evacuation.

Option 6 is the use of slanted earth-sheltered residences and small commercial buildings. Once a decision has been made to adopt earth-sheltered structures for their energy conservation or aesthetic features, the modification of the design to provide fallout protection and modest levels of blast-upgradable capability involves very little additional expense. It has been estimated by Chester, Shapira, Cristy, Schweitzer, Carnes, and

Torri-Safdie (1983) that such shelter could be produced using this approach for $60 or less per space. Earth-sheltered construction is applicable almost anywhere there is land available to build detached dwellings; it has the potential for sheltering the entire population.

The advantage of this approach is the cost per space and the fact that an aggressive Federal program of incentives, which succeeded in mobilizing the entire housing industry, could produce enough space in two years for the entire population. The Federal incentive payment to replace frame construction with earth-sheltered construction would cost approximately $300 per space.

A major drawback to this approach is that it would be necessary for people who participated in this program to accept others into their home during the crisis. Agreements between the homeowner and the government to accept a Federal subsidy in exchange for accepting refugees in a crisis would have to be carefully worded to avoid a legal challenge.

Option 7 involves dual-use basements in new construction. In this option, the entire basement in new buildings would be hardened to whatever level of weapons effects is expected: approximately 30 to 50 psi in target areas. The incremental cost per space is estimated in various studies from $250 to $750 (in 1985 dollars). The technique is applicable to the entire population; although, fully developed downtown areas may not have enough construction for several decades to provide new basement space for their entire population. The major advantages to this approach are cost and construction of the shelter space where shelter is needed. It is also applicable over the entire nation whenever basements are feasible.

The main disadvantage to this approach is that there may be rubble and fire problems for such shelters in central cities. It would also take several years to build enough of this space even assuming that Federal funding was not limited. Costs will be higher in areas with high water tables.

Option 8, a Swiss basement shelter in new construction, is a carbon copy of the Swiss program. One or more rooms are constructed of concrete in the basement of new buildings to provide sufficient shelter area for the expected occupants of the building. It is estimated by the Swiss that their program costs between $350 and $500 per space (Federal Office of Civil Defense, 1983, 1985; Heinzmann, 1985). This cost, developed after 25 years of construction experience in Switzerland, does include blast valves and rather elaborate air filtration equipment.

The Swiss shelter system has the great advantage of requiring only minutes of warning, since the shelter is located very close to the people. The largest disadvantage is the cost, which implies a program of $80 billion. Shelters under basements also are put at risk from rubble and fire unless they are very carefully designed with rather elaborate escape tunnels and air intakes. The other disadvantage is that the price of even $500 per space is only possible when it is constructed in the course of new construction. To turn over the U.S. inventory of buildings may take from 30 to 50 years in some areas.

Option 9 is a retrofit family blast shelter program. The estimated cost varies from $500 to $2500 per space, depending on the type of shelter and the number of people that would be using it. It would be applicable to that part of the population that live in one- and two-family detached dwellings, approximately 160 million people. Its advantage is that it could be deployed in approximately 2 years.

The system of family shelters, supplemented by some other shelter construction in the multi-family housing areas, has the advantage that it would be very effective with only tactical warning of a nuclear attack. It has the disadvantage that the cost becomes fairly substantial, even at $500 per space characteristic of corrugated metal shelters. A program to house the entire population would cost $120 billion. The more elaborate dual-use family shelters can cost upwards of $2000 per space implying a national program of almost $500 billion. The retrofit family blast shelter generally requires a detached dwelling (a yard to dig in) and is not applicable in most built-up central cities.

Option 10 is the construction of single-purpose shelters holding from 100 to a few thousand people. These can be constructed as concrete pipes, corrugated metal arches, or concrete boxes belowgrade or bermed. A number of studies have estimated the cost of this type of structure for critical workers as $1500 to $2500 per space, although this price should come down in a large program and for larger numbers of shelters. It would be applicable in most places, except densely built-up central cities. Its principal advantage would be a relatively rapid deployment,perhaps 2 to 5 years, since it doesn't depend on the construction of new buildings. The principal disadvantage is cost; a program relying exclusively on this technique for the entire population would cost more than a Swiss program.

Option 11 is the construction of interconnected tunnel shelters under cities. This has been proposed by a few American investigators and has apparently been carried out to a considerable extent by the Chinese under their major cities. The cost is high, approximately $2000 per space. If the program were poorly managed, it could escalate to several times this amount. The system would be only used in very high density population areas, since its cost per space becomes prohibitive in low population densities.

This program produces the Cadillac of civil defense shelters. Given enough entryways, people can get into this system in a very few minutes. The interconnectedness of the system gives excellent protection against rubble and fire: if one entryway or ventilation air intake is blocked or in a fire, then it can be simply closed off and air drawn through the tunnel from other unblocked ventilation intakes. It also permits movement within the shelter system so that very high-density population can be moved out to lower density areas.

To a first approximation these different shelter options can be broken down into three classes: (1) those in the range of 1 to 20 dollars per space, (2) those in the range of a few hundred dollars per space, and (3) those in the low thousands of dollars per space. Those costing one to a few dollars per space, if acquired over several years, imply an annual expenditure in the vicinity of FEMA's present total budget. Useful space could then be developed with only a modest increase in FEMA's budget. Shelter options falling under this category are the dissemination of crisis upgrading information, the dissemination of the expedient shelter information and plans, and the low end of modifying quarrying activities near cities.

Shelter options costing a few hundred dollars per space involve an expenditure for the entire population of a few tens of billions of dollars spread over ten years. Annual expenditures for civil defense approximating 1% of the 1986 Defense budget would be required. This amount is the low end of the expenditure on major strategic systems. Monies in these quantities might become available if the United States decides to deploy a ballistic missile defense and go generally to a defensive strategic posture. Shelter options in this category include earth-sheltered structures, dual-use basements in new construction, and Swiss basement shelters in new construction.

Systems requiring $1000 or more per space imply total expenditures of hundreds of billions of dollars and are unlikely for the whole population under present circumstances. Shelter options in this category include retrofit family shelters, retrofit dedicated blast shelters, and tunnel shelters under cities. Shelters of these types may be built by wealthy individuals or do-it-yourselfers or constructed for small numbers of selected personnel required to remain in very high risk areas in a crisis (critical workers).

9. RESEARCH AND DEVELOPMENT RECOMMENDATIONS

While a great deal is known about shelter from nuclear weapons as a result of extensive research conducted over the past 40 years, there is room for additional work. In addition to important gaps in knowledge (e.g., the potential for the production of shelter space by changes in concrete aggregate mining practices around cities), there have also been changes in the threat and the possibility of dramatic changes in the political and economic environment in the country.

The threat is changing from large-yield weapons fired against urban areas to intermediate-range weapons targeted with greatly improved accuracy on more specific industrial concentrations and military targets.The advent of the cruise missile means that an active defense system is apt to cause many nuclear explosions outside of presently recognized risk areas. There is indication that the biological weapon threat may need to be reconsidered. Lastly, the upsurge of terrorism, including that not related to the Soviet Union, holds the potential for large-scale threats against civilian populations involving either nuclear, biological, or chemical weapons.

The political and economic climate may change in such a way that interest in shelter is restored. In particular, if the President's research program on missile defense (the Strategic Defense Initiative) proves that a defensively oriented strategy is technically feasible, a "bottom layer"of passive defenses for the civilian population is logically unavoidable.

9.1 ADAPTION OF MINES FOR SHELTER

A review should be made of concrete aggregate mining practices in the vicinities of population concentrations. Those mining areas where the geological formations permit conversion from open-pit mining to sub-surface mining should be identified and the cost of the conversion estimated. Monetary and other incentives for the conversion should be explored with the possibility of recommending its incorporation in the FEMA program.

The information data base on caves maintained by the American Speleological Society should be reexamined and the identification of potential shelter areas brought up to date.

9.2 SLANTING SHELTER BUILDING EXPERIENCE

Experience in shelter construction should be obtained, including actual construction of slanted shelter space in buildings built with 1980-1990 technology. In particular, some actual earth-sheltered residences or small commercial buildings should be constructed using designs slanted for protection against nuclear weapons. It is expected that the cost to the government in this endeavor would be that of providing architectural services to those who want to build earth-sheltered or slanted earth-sheltered residences and that of documenting the construction and costs.

9.3 PLANS FOR PRIVATE CITIZENS

An ongoing effort to expand and maintain a compendium of family shelter plans which would be available to private citizens on request should be established. The plans should be on 8-1/2 X 11 sheets to permit economical reproduction on widely available commercial copiers and should include documentation of construction experience, cost, and critique by experts where available. Emphasis should be on dual-use construction with peacetime functions such as root cellars, wine cellars, study, music room, etc.

9.4 HABITABILITY TESTING

It has been decades since experiments have been done with people actually living in shelters for more than a day or two. Some experience should be obtained with modern habitability equipment, particularly that developed for recreation vehicles and boats, such as improved equipment for sanitation, lighting, electrical power generation, water storage and purification, and bedding. The same is true for the expedient versions of these technologies.

9.5 BLAST TESTING

In addition to habitability testing, an ongoing program of blast testing new or modified shelter concepts, in conjunction with the large Defense Nuclear Agency field tests, should be maintained. Without continual exposure to reality, knowledge tends to deteriorate as important details are forgotten or left out of revised plans. In addition, the expert personnel disappear due either to reassignment or retirement. While much detail can be stored in handbooks, some live experts can obviate the need for reinventing solutions to unanticipated problems in the field.

BIBLIOGRAPHY

EXPLANATORY MATERIALS FOR BIBLIOGRAPHY

All references contained in the body of this report are quoted using either the format of AUTHOR (YEAR) or the format of (AUTHOR, YEAR). AUTHOR will be the last name(s) of the author(s) of the reference, and YEAR will be the year of publication. In order to avoid ambiguity in certain cases, some references are also given with an author's first name or initials or with both a month and a year.

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Any of the publications by the Federal Emergency Management Agency (FEMA), including existing shelter plans (the H-12 series), are available, subject to quantities in stock, from:

FEMA, Publications Office,
P.O. Box 8181,
Washington, DC 20024.

The current FEMA Publications Catalog is available as document FEMA-20.

Those references which are contained in this bibliography and which did not directly result from government-sponsored research (such as journal articles and privately published books) must be obtained from other sources.

Interested readers are referred to the following documents for additional bibliographic information: Defense Documentation Center (1972); Gailar (1970); Mitchell (1961) National Technical Information Service (1984); U.S. Naval Civil Engineering Laboratory (1964).

BIBLIOGRAPHY

Abbey, R.F., Jr., "Risk Probabilities Associated with Tornado Windspeeds," pp. 117-237 in *Proceedings of the Symposium on Tornadoes -- Assessment of Knowledge and Implications for Man* (a conference held June 22-24, 1976, in Lubbock, Texas), NSF/RA-761633 (PB290099), published by Institute for Disaster Research, Texas Tech University, Lubbock, TX, 1976.

Abbott, L.S., *Shielding Against Initial Radiations from Nuclear Explosions*, ORNL-RSIC-36, Oak Ridge National Laboratory, Radiation Shielding Information Center, Oak Ridge, TN, July 1973.

Agbabian-Jacobsen Associates, *Study of Shock Isolation for Hardened Structures*, AJA-6424, Los Angeles, CA, June 1966.

Akimov, N.I., *Civil Defense, Moscow -- 1969*, (translated from Russian by S.J. Rimshaw), ORNL-TR-2306, Oak Ridge National Laboratory, Oak Ridge, TN, April 1971.

Albert, T.E., L. Huszar, and G.L. Simmons, *Sensitivity of INR Shielding Analyses to Source and Structural Variations*, SAI-77-867-LJ (AD-A050693), prepared for the Defense Civil Preparedness Agency by Science Applications, Inc., La Jolla, CA, December 1977.

Alboth, H., "Civil Defence -- Focal Point of Norway's National Defence System," *AEGIS International (Switzerland)* *4* (6), pp. 16-21 (December 1984/January 1985).

Albright, G.H. (ed.), *Planning Atomic Shelters: A Guidebook for Architects and Engineers*, published by Pennsylvania State University Press, University Park, PA, 1961.

Albright, G.H., et al., *Measurement of Natural Draft*, AD-429796, prepared for Office of Civil Defense by Pennsylvania State University, College of Engineering, University Park, PA, December 1963.

Albright, G.H., E.J. Beck, J.C. LeDoux, and R.A. Mitchell, *Evaluation of Buried Corrugated-Steel Arch Structures and Associated Components* (Operation PLUMBBOB, Project 3.3), WT-1422, (AD-615737), U.S. Department of the Navy, Bureau of Yards and Docks, Washington, DC, and U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, February 1961.

Albright, G.H., J.C. LeDoux, and R.A. Mitchell, Evaluation of Buried Conduits as Personnel Shelters (Operation PLUMBBOB, Project 3.2), WT-1421 (AD-691406), U.S. Department of the Navy, Bureau of Yards and Docks, Washington, DC, and U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, July 1960.

Albritton, G.E., and J.P. Balsara, Response of Buried Vertically Oriented Cylinders to Dynamic Loading, AD-A090354, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, June 1980.

Albritton, G.E., J.L. Kirkland, T.E. Kennedy, and A.F. Dorris, The Elastic Response of Buried Cylinders; Critical Literature Review and Pilot Study, TR-1-720, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, April 1966.

Allen, F.C., "Environmental Control for Survival," Chapter 11 in ASHRAE Handbook -- 1982 Applications, published by American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA, 1982.

Allen, F.C., Parametric Study of Thermal Problems in Densely Populated Shelters (Final Report), SRI Project URU-1218 (AD-749796), Stanford Research Institute, Menlo Park, CA, June 1972.

Allen, F.C., Ventilating and Mixing Processes in Nonuniform Shelter Environments (Final Report), SRI Project MU-7327 (AD--708574) prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, January 1970.

Allen, F.C., A.M. Hatch, D.E. Keyt, and D.P. Rohrer, Test and Evaluation of Antiblast Valves for Protective Ventilating Systems (Operation PLUMBBOB, Preliminary Report, Project 31.5), ITR-1460, Federal Civil Defense Administration, Washington, DC, August 1958.

Allgood, J.R., Summary of Soil-Structure Interaction, NCEL-TR-771 (AD-748581), U. S. Naval Civil Engineering Laboratory, Port Hueneme, CA, July 1972.

Allgood, J.R., R.M. Webb, and R.F. Swalley, Design for a Cast-in-Place Concrete Shelter, NCEL-TR-191, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, December 1962.

Allgood, J.R., C.R. White, R.F. Swalley, and H.L. Gill, Blast Loading of Small Buried Arches (Final Report), NCEL-TR-216, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, April 1963.

Altman, J.W., R.W. Smith, R.L. Meyers, F.S. McKenna, and S. S. Bryson, Psychological and Social Adjustment in a Simulated Shelter, AD-270144, prepared for Office of Civil and Defense Mobilization by American Institutes for Research, Pittsburgh, PA, July 1961.

Ambrose, J. E., and G. E. Commerford, The Study and Evaluation of Absorption-based Cooling Systems for Use in Civil Defense Shelters (Final Report -- 1 July 1964 to 31 July 1965), SWRI Project 01-1580 (AD-625436), prepared for Stanford Research Institute by Southwest Research Institute, San Antonio, TX, December 1965.

American Institute of Architects, 1969 Architectural Awards: Buildings with Fallout Shelter, TR-63, Office of Civil Defense, Washington, DC, July 1970.

American Iron and Steel Institute, Handbook of Steel Drainage and Highway Construction Products (Second Edition), published for the AISI by R.R. Donelley and Sons, Co.; The Lakeside Press: New York, NY 1973.

American Machine and Foundry Company, Investigations Concerning Feasibility of Various Designs for a Blast Closure Device, NBy-13030 (AD-654577), prepared for the U.S. Department of the Navy, Bureau of Yards and Docks, by American Machine and Foundry Co., Greenwich, CT, June 1958.

American Society of Civil Engineers, Design of Structures to Resist Nuclear Weapons Effects (Revised Edition), ASCE Manuals and Reports on Engineering Practice No. 42, published by ASCE (345 East 47th St.), New York, NY 1985.

Ammann and Whitney, An Introduction to Protective Design for Nuclear Weapons Effects (Professional Manual Series), PM-100-5, prepared for Office of Civil Defense by Ammann and Whitney, New York, NY, April 1965.

Ammann and Whitney, Modification of Existing Buildings as Community Shelters (Professional Guide Series), PG-80-3, prepared for Office of Civil Defense by Ammann and Whitney, New York, NY, January 1965.

Ammann and Whitney, Study of Shock Isolation Methods for Civil Defense Shelters, AD-428009, prepared for Department of Army, Office of the Chief Engineers and Office of Civil Defense by Ammann and Whitney, New York, NY, November 1963.

Ammann and Whitney, Engineering Study of Atomic Blast Resistant Design for Several Different Building Types, AD-625752, prepared for Department of the Army by Ammann and Whitney, New York, March 1960.

Anderson, B., "Waterproofing Materials and Techniques for Cut-and-Cover Structures," Underground Space 8 (2), pp. 99-110, (1984).

Anderson, F.E., Jr., R.J. Hansen, H.L. Murphy, N.M. Newmark, and M.P. White, Design of Structures to Resist Nuclear Weapons Effects, ASCE Manuals of Engineering Practice No. 42, American Society of Civil Engineers, Committee on Structural Dynamics of the Engineering Mechanics Division, New York, NY, 1961.

Andon, J., Test and Evaluation of the Modified OCD Blast Closure Valves, NCEL-TN-779 (AD-475769), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, November 1965.

Arthur D. Little, Inc., Anti-Blast Valve Development: 1960-1964 (Summary of Research Report), AD-447115, Cambridge, MA, September 1964.

ASHRAE Task Group on Survival Shelters, Symposium on Survival Shelters (held June 25-27, 1962, in Miami Beach, FL), AD-334065, published by American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, NY, 1963.

Asplin, L.I., and W.L. Brooks, Evaluation of the German Coarse Sand Filter (Engineering Group Report), ENGR. No. 56 (AD-400118), U.S. Army Chemical-Biological-Radiological Engineering Group, Army Chemical Center, MD, March 1963.

Auxier, J.A., J.O. Buchanan, C. Eisenhauer, and H.E. Menker, Experimental Evaluation of the Radiation Protection Afforded by Residential Structures Against Distributed Sources, CEX-58.1, Oak Ridge National Laboratory, Oak Ridge, TN, and U.S. Atomic Energy Commission, Washington, DC, September 1958.

Auxier, J.A., Z.G. Burson, R.L. French, F.F. Haywood, L.G. Mooney, and E.A. Straker, Nuclear Weapon Free-Field Environment Recommended for Initial Nuclear Radiation Shielding Calculations, ORNL-TM-3396, Oak Ridge National Laboratory, Oak Ridge, TN, February 1972.

Avise, H.J., Development of a Shelter Blast and Fire Vulnerability Data Systems, SYSSCI-71-17 (AD-740805), System Sciences, Inc., Bethesda, MD, November 1971.

Avise, H.J., et al., Shelter System Performance in Urban Environments, AD-886524, System Sciences, Inc., Bethesda, MD, April 1971.

Bagge, C.F., Design Consideration for Deep Underground Protective Facilities, Technical Report No. 8 (AD-744790), prepared for Corps of Engineers, Omaha District, by Agbabian-Jacobsen Associates, Los Angeles, CA, March 1972.

Baker, O.J., R.W. Heck, T.M. McQueen, F.E. Metz, and P.D. Stand, Single Family Above-Ground Fallout Shelters for the Gulf Coast: Construction and Testing, Contract No. OCD-OS-63-112, prepared for Office of Civil Defense by Louisiana State University, Department of Architecture, Baton Rouge, LA, November 1964.

Baker, S.A., and M.B. May, Impact Warning and Miscellaneous Shelter Topics, AD-888130, Office of Civil Defense, Washington, DC, July 1971.

Bakos, J.D., Jr., Dynamic Response of a Small Shear Wall Structure, Technical Report N-69-7 (AD-863820), U.S. Army Engineer Waterways Station, Vicksburg, MS, November 1969.

Baldwin, D.B., Soil Thermal Conductivity Investigation for Underground Shelters, PSDC-TR-13 (AD-661090), prepared for Office of Civil Defense by Protective Structures Development Center, Washington, DC, March 1967.

Ball, J.W., Proof Test of Military Shelter Concepts (Middle North Series, MIXED COMPANY Event; Project Officers Report LN30), DNA-POR-6602-2 (AD-B000534), prepared for Defense Nuclear Agency by U.S. Army Engineer Waterways Experiment Station, Weapons Laboratory, Vicksburg, MS, August 1974.

Barber, E.M., T. Kusuda, P.J. Reynolds, and F.J. Powell, A Study of Air Distribution in Survival Shelters Using a Small-Scale Modeling Technique (Final Report), NBS Report 10-689 (AD-741382), prepared for Office of Civil Defense by National Bureau of Standards, Washington, DC, February 1972.

Barber, G.R., Jr., and G.N. Sisson, Planning Guide -- Essential Worker Shelter, FEMA Contract EMW-84-C-1590, prepared for the Federal Emergency Management Agency by Center for Planning and Research, Inc., Falls Church, VA, August 1985.

Barker, M.B., "Earth-Sheltered Construction: Thoughts on Public Policy Issues," Underground Space 4 (5), pp. 283-88 (1980).

Barksdale, B.H., Jr., and S.R. Wade, Methods of Shelter Cost Analysis (Final Report), AD-646847, prepared for Office of Civil Defense by Hayes, Mattern and Mattern, Roanoke, VA, February 1967.

Barnard, J., "Earth Sheltering in the Eastern United States," pp. 109-127 in Underground Space Conference and Exposition (held in Kansas City, MO, June 8, 1981), CONF-810671-1, (1981).

Barnett, R.L., Feasibility of Tunnel Closures, ARF Project K138 (AD-276481), prepared for the Office of Civil and Defense Mobilization by Armour Research Foundation of IIT Research Institute, Chicago, IL, November 1958.

Baschiere, R.J., B.A. Humphreys, K.E. McKee, and E. Vey, Evaluation of Deep Tunnel Shelters (Final Report), ARF Project No. K149 (AD-276484), prepared for Office Civil and Defense Mobilization by Armour Research Foundation of IIT Research Institute, Chicago, IL, November 1958.

Baschiere, R.J., and M. Lokmanhekim, Shelter Forced Ventilation Using Unconditioned Air, GARD Report 1266 (AD-661096), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, December 1964.

Baschiere, R.J., M. Lokmanhekim, and H.C. Moy, Analysis of Aboveground Fallout Shelter Ventilation Requirements, GATC Final Report MRD-1240-1 (AD-461858), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, December 1964.

Baschiere, R.J., C.E. Rathmann, and M. Lokmanhekim, Adequacy of Evaporative Cooling and Shelter Environmental Prediction, GARD Final Report 1423 (AD-679874), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, June 1968.

Basic Military Knowledge Writing Group (China), Chinese Civil Defense (a translation from Chinese of Chapter 7 and a part of Chapter 3; edited by C.V. Chester and C.H. Kearny), ORNL-TR-4171, Oak Ridge National Laboratory, Oak Ridge, TN, September 1974.

Batchelor, W.D., Gateway to Survival is Storage, published by Hawkes Publishing, Inc. (P.O. Box 15711), Salt Lake City, UT, 1974.

Bauer, E., "BUYER'S GUIDE: Survival Module Construction -- New Forge Works, Claypole, Newark, Notts., Great Britain," Protect and Survive Monthly (United Kingdom) 1 (10), pp. 16-17 (October 1981).

Beavers, J.E., and G.E. Albritton, Response of Deep Two-Way Reinforced and Unreinforced Concrete Slabs to Static and Dynamic Loading: Report 5, Static Tests of Deep Square Composite Slabs, AEWES-TR-N-69-2-5 (AD-877404), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, September 1970.

Bechtel Corporation, Final Report for Protective Blast Shelter System Analysis - Detroit, Michigan, AD-674254, prepared for Office of Civil Defense by the Bechtel Corporation, Gaithersburg, MD, June 1968.

Bechtel Corporation, Final Study Report for Protective Blast Shelter System Analysis, AD-656625, prepared for Office of Civil Defense by the Bechtel Corporation, Gaithersburg, MD, April 1967.

Beck, C. (ed.), Nuclear Weapons Effects Tests of Blast Type Shelters -- A Documentary Compendium of Test Reports, CEX-68.3, U.S. Atomic Energy Commission, Washington, DC, June 1969.

Beck, E.J., Jr., Gravity Ventilation of Protective Shelters, NCEL-TN- 471 (AD-414093), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, July 1963.

Beer, M., and M.O. Cohen, Additional Adjoint Monte Carlo Studies of the Shielding of Concrete Structures Against Initial Gamma Radiation, MR-7043 (AD-A014504), prepared for Defense Civil Preparedness Agency by Mathematical Applications Group, Inc., Elmsford, NY, February 1975.

Beer, M., and M.O. Cohen, Initial Gamma Radiation Dose in Five Concrete Structures, MR-7037 (AD-771324), prepared for Defense Civil Preparedness Agency by Mathematical Applications Group, Inc., Elmsford, NY, November 1973.

Behls, H.F., and G. Engholm, Design, Specifications and Cost Analysis for OCD Shelter Test Equipment, GATC Report MRD-1233, (AD-446235), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, December 1963.

Behls, H.F., B.A. Libovicz, and G. Engholm, Summer Ventilation Test of a Corridor-Type Fallout Shelter in Milwaukee, Wisconsin, GATC-IR-MRD-1195-54-1, (AD-450914), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, September 1964.

Behls, H.F., B.A. Libovicz, and G. Engholm, Ventilation Test of a 300-Man Belowgrade Fallout Shelter in Wilmington, North Carolina, GATC-IR-MRD-1195-55-2, (AD-450951), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, April 1964.

Behls, H.F., and C.A. Madson, Experimental Studies of Fallout Shelter Ventilation Requirements, GARD-1268-40, (AD-630423), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, October 1965.

Behr, R.A., and E.W. Kiesling, "Estimated Cost of Earth-Covered Arch and Dome Shells," Underground Space 9 (1), pp. 45-50 (1985).

Bennedsen, M.B., Preliminary Engineering Procedures and Costs for Integrating 30-psi Fallout Shelter into Normal First Floor Plans During Original Construction for New Buildings in Downtown Norfolk, Virginia, (Technical Report No. 2) SRI Project No. IM-4075, prepared for Norfolk Redevelopment and Housing Authority by Stanford Research Institute, Menlo Park, CA, November 1962a.

Bennedsen, M.B., Preliminary Design of a Semi-Buried Parking Garage and 30 Psi Fallout Shelter for 40 People (Technical Report No. 4), SRI Project No. IM-4075, prepared for Norfolk Redevelopment and Housing Authority by Stanford Research Institute, Menlo Park, CA, November 1962b.

Bernard, R.D., and C. Wilton, The Effects of Building Collapse on Basement Shelters in Tall Buildings (Final Report), SSI-8130-8 (AD-A124293), prepared for Federal Emergency Management Agency by Scientific Service Inc., Redwood City, CA, January 1983.

Biderman, A.D., M. Louria, and J. Bacchus, Historical Incidents of Extreme Overcrowding, BSSR-354-5 (AD-609752), Bureau of Social Science Research, Inc., Washington, DC, March 1963.

Bigelow, C.D., The Potential of Mass Production for Reducing Costs Shelter Construction -- A Preliminary Survey, SRI Project MU-4949-021 (AD-625238), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, March 1965.

Bigger, M.M., R.J. Crew, and R.K. Fuller, Non-Ingested Dose Associated with Particulate Ingress into a Prototype Shelter via the Ventilation System, USNRDL-TR-815 (AD-459461), U.S. Naval Radiological Defense Laboratory, San Francisco, CA, January 1965.

Black, M.S., Evaluation of Expedient Techniques for Strengthening Floor Joist Systems in Residential Dwellings (Final Report), Miscellaneous Paper N-75-6 (AD-A013987), prepared for Defense Civil Preparedness Agency by U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS, July 1975.

Blackett, D.A., Feasibility Study Concerning the Utilization of Plastics for Underground Personnel Shelters, NBy-3150 (AD-2287-06), prepared for Naval Civil Engineering Research and Evaluation Laboratory by Massachusetts Institute of Technology, Cambridge Structural Analysis Laboratory, Cambridge, MA, September 1959.

Blanchard, B.W., American Civil Defense 1945-1975, The Evolution of Programs and Policies, a Doctoral Dissertation for University of Virginia, Department of Government and Foreign Affairs, Charlottesville, VA, May 1980.

Blohm, C.L., Human Waste Sanitation Studies: Final Report -- 4 April 1964 to 1 June 1965, AD-706931, prepared for United States Army Engineer Research and Development Laboratories by Truesdail Laboratories, Inc., Los Angeles, CA, May 1965.

Bobrow, S.B., The Capability, Credibility, and Desirability of Blast Shelter Systems: A System for Analysis, ORNL-TM-1089, Oak Ridge National Laboratory, Oak Ridge, TN, May 1965.

Boegly, W.J., Jr., W.L. Griffith, and K.P. Nelson, Conceptual Design of a Dual-Use Utility Tunnel Blast Shelter for White Plains, New York, ORNL-4362, Oak Ridge National Laboratory, Oak Ridge, TN, March 1969.

Bogardus, H.F., (ed.) Studies of the Naval Facilities Engineering Command Protective Shelter -- II. Summer Trials, NRL-6656 (AD-669448), Naval Research Laboratory, Washington, DC, March 1968.

Bothun, R.B., Factors Affecting Shelter Costs, SRI Project IU-1947-ID, prepared for Federal Civil Defense Administration by Stanford Research Institute, Menlo Park, CA, December 1957.

Bousek, R.R. (ed.), Proceedings of the DISTANT RUNNER Symposium, 27-28, April 1982, DNA-POR-7063 (AD-B069757), Defense Nuclear Agency, Kirtland Air Force Base, NM, September 1982.

Brannon, J.D., and M.L. Scala, Shelter Mix Requirements (Key U.S. Industrial Workers), USAESC-R-84-6, prepared for the Federal Emergency Management Agency by U.S. Army Engineer Studies Center, Fort Belvoir, VA, June 1984.

Breck, R.S., Shelter Air Conditioning Unit (Final Report), AD-659428, prepared for Office of Civil Defense by Carrier Air Conditioning Company, Special Products Division, Syracuse, NY, February 1967.

Breckenridge, R.A., Preliminary Development and Tests of a Blast-Closure Valve, NCEL-TN-460, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, September 1962.

Brode, H.L., "The Real Thing: Blast Waves from Atmospheric Nuclear Explosions," pp. 31-47 in Shock Tubes and Waves (Proceedings of the 12th International Symposium on Shock Tubes and Waves, Jerusalem, Israel, July 16-19, 1979), AFOSR-TR-80-1141 (AD-A091010), Air Force Office of Scientific Research, Bolling Air Force Base, DC, February 1980.

Brode, H.L., "Review of Nuclear Weapons Effects," Annual Review of Nuclear Science 18, pp. 153-202 (1968).

Brode, H.L., A Review of Nuclear Explosion Phenomena Pertinent to Protective Construction, R-425-PR, prepared for U.S. Department of Defense by Rand Corporation, Santa Monica, CA, May 1964.

Broido, A., and A.W. McMasters, Effects of Mass Fires on Personnel in Shelters, Technical Paper No. 50 (AD-254070), Pacific Southwest Forest and Range Experiment Station, Forest Service, USDA, Berkely, CA, August 1960.

Brotchie, J.F., A. Jacobson, and S. Okubo, Effect of Membrane Action on Slab Behavior, NCEL-TR-65-25, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, August 1965.

Brotherson, D.E., R.N. Wright, and S.D. Pecora, Limited Blast Resistance in Houses (Final Report), Research Report 68-1, prepared for Office of Civil Defense by University of Illinois, Urbana-Champaign, IL, December 1968.

Brown, D., Blast Shelter Concept II (Revised), published by Donn Corporation, Westlake, OH, December 1978.

Brown, W.M., Deferred-Cost Civil Defense Options for Nuclear Crises, HI-614-RR, prepared for Office of Civil Defense by Hudson Institute, Inc., Croton-on-Hudson, NY, January 1967.

Brown, W.M., A New Look at the Design of Low Budget Civil Defense Systems, HI-478-RR, prepared for Office of Civil Defense by Hudson Institute, Inc., Harmon-on-Hudson, NY, August 1965a.

Brown, W.M., A Model for Active-Passive Defense, HI-579-RR-REV, Hudson Institute, Harmon-on-Hudson, NY, August 1965b.

Brown, W.M., Some Aspects of Effectiveness of Active-Passive Programs, HI-381-RR, Hudson Institute, Harmon-on-Hudson, NY, July 1964.

Brown, W.M., Alternate Civil Defense Programs and Postures, HI-361-RR/1 (AD-602847), prepared for Office of Civil Defense by Hudson Institute, Inc., Harmon-on-Hudson, NY, June 1964a.

Brown, W.M., The Design and Performance of "Optimum" Blast Shelter Programs (Final Report), HI-361-RR/2 (AD-602850), Hudson Institute,Inc., Harmon-on-Hudson, NY, June 1964b.

Brown, W.M., and M.S. Black, Dynamic Strength Study of Small Fixed-Edge, Longitudinally Restrained Two-Way Reinforced Concrete Slabs (Final Report) Technical Report N-73-8 (AD-774848), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, December 1973.

Bruce, R.N., Jr., J.E. Branch, M.P. Gronbeck, J.T. Hanley, and D.F. McCahill, An Investigation of School Designs to Resist Integrated Nuclear Weapons Effects, TR-100 (AD-626770), prepared for Office of Civil Defense, by Tulane University, Department of Civil Engineering, New Orleans, LA, October 1965.

Brusse, J.C., A Study of the Infiltration of Radioactive Fallout Particles into Shelter Spaces Through Large Openings, AD-446628, prepared for Office of Civil Defense by Texas A&M University, Texas Engineering Experiment Station, College Station, TX, June 1964.

Bucci, D.R., Improved Portable CP Bunker (Airmobile), Miscellaneous Paper SL-79-10 (AD-B037632), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, May 1979.

Bucci, D.R., Response of Foam-Layered Earth-Covered Structures to Contact Burst Rounds, Miscellaneous Paper SL-79-8 (AD-B0382-03), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, April 1979.

Buday, J.M., Study of Alternate Material Pedal Ventilator Kits (Final Report), GARD-A1-16/1724 (AD-A086753), prepared for Federal Emergency Management Agency by GARD, Inc., Niles, IL, April 1980.

Buday, J.M., and R.J. Klima, Development of Two Types of Ventilators, GARD Final Report No. 1703 (AD-A071839), prepared for Defense Civil Preparedness Agency by GARD, Inc., Niles, IL, April 1979.

Bultmann, E.H., Jr., E. Sevin, and T.H. Schiffmann, Blast Effects on Existing UPSHOT-KNOTHOLE and TEAPOT Structures (Operation PLUMBBOB, Project 3.4), WT-1423, Armour Research Foundation, Chicago, IL, and Air Force Special Weapons Center, Kirtland Air Force Base, NM, no date.

Burson, Z.G., Comparison of Measurements in Above-Ground and Below-Ground Structures from Simulated and Actual Fallout Radiation -- Experimental Radiation Measurements in Conventional Structures, Part II, CEX-59.7B, Edgerton, Germeshausen and Grier, Inc., Las Vegas, NV, February 1963.

Burson, Z., and H. Borella, Experimental Evaluation of the Radiation Protection Provided by an Earth-Covered Shelter, CEX-60.6, Edgerton, Germeshausen and Grier, Inc., Santa Barbara, CA, April 1961.

Byrnes, J.B., Effects of an Atomic Explosion on Underground and Basement Types of Home Shelters (Operation UPSHOT-KNOTHOLE, Project 21.1), WT-801 (AD-A074624), Federal Civil Defense Administration, Washington, DC, October 1953.

Cabraal, R.A., A.S. Dhaliwal, and E. Faby, Estimation of Critical Population Support Requirements (Final Report), TR-008-84, prepared for Federal Emergency Management Agency by Engineering and Economics Research, Inc., Vienna, VA, May 1984.

Cain, V. R., A Study of the Radiation Shielding Characteristics of Basic Concrete Structures at the Tower Shielding Facility, ORNL-3464 (AD-428230), Oak Ridge National Laboratory, Oak Ridge, TN, January 1964.

Cain, V.R., C.E. Clifford, and L.B. Holland, Measurements of Radiation Intensities in Vertical Concrete-Lined Holes and an Adjoining Tunnel at the Tower Shielding Facility, ORNL-3513 (AD-428330), Oak Ridge National Laboratory, Oak Ridge, TN, March 1964.

Callahan, E.D., L. Rosenblum, and J.R. Coombe, Shelter From Fallout, TO-B60-30 (AD-276392), Technical Operations, Inc., Burlington, MA, April 1961.

Cameron, R.A., Jr., and P.H. Huff, Radiation Shielding and Response Studies of AEC Test Structures (Operation HARDTACK, Project 34.2), WT-1723, Holmes and Narver, Inc., Los Angeles, CA, June 1962.

Cameron, R.A., Jr., and P.H. Huff, Physical Damage Survey of AEC Test Structures (Operation HARDTACK -- Project 34.1), WT-1701, Holmes and Narver, Inc., Los Angeles, CA, May 1962.

Canada, C.E., and M. McVay, Optimal Design of Shallow-Buried Structures Subjected to the Effects of a Nuclear Detonation, Miscellaneous Paper SL-85-19, prepared for Defense Nuclear Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, December 1985.

Canada Emergency Planning, Eleven Steps to Survival, Cat. No. D83-1/4-1980E, Ottawa, Canada, 1980.

Cannell, R.S., LIVE -- A Handbook of Survival in a Nuclear Attack, published by Prentice-Hall, Inc., Englewood Cliffs, NJ, 1962.

Carmody, J., and R. Sterling, Earth Sheltered Housing Design (Second Edition), published by Van Nostrand Reinhold Co., New York, NY, for the University of Minnesota, Underground Space Center, 1985.

Carre, G.L., Application of Field Available Materials to Fortifications, Technical Report N-74-4 (AD-780735), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, May 1974.

Carroll, T.P., F. Farahti, and S.J. Gallagher, Alternate Blast Shelter Design Specifications and Cost Analysis, CA-145-1, prepared for the Federal Emergency Management Agency by T. Carroll Associates, Inc., Bethesda, MD, May 1985.

Caughron, R. D., Y. Chung, Water Requirements of the Flush Toilet -- Alternative Sanitation Systems for Emergency Shelters: A Review and Evaluation of the Literature (Final Report), SERL Report No. 67-13 (AD-828681), prepared for Office of Civil Defense by University of California Sanitary Engineering Research Laboratory, Berkeley, CA, July 1967.

Cecil, S. R., Storage Stability of Civil Defense Shelter Rations (Annual Report), Technical Report 156-VI-GES (AD-673817), prepared for Office of Civil Defense by University of Georgia, College of Agriculture Experiment Stations, Georgia Experiment Station, GA, June 1968.

Central Mortgage and Housing Corporation (Canada), *Fallout Shelter for Use in the Designs of New Homes -- Blueprint for Survival No. 2*, prepared for the Emergency Measures Organization by Central Mortgage and Housing Co., Ottawa, Canada, March 1959.

Chapler, R.S., *Evaluation of Four Blast Closure Valves*, NCEL-TR-347, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, January 1965.

Chapman, J.M., *Gamma Dose Rates and Energy Spectra in a 3-Foot Square Duct*, NCEL-TN-443 (AD-278119), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, June 1962.

Charanian, T.R., A.J. Glueckert, R.G. Barile, and J.D. Zeff, *Environmental Control Systems for Closed Underground Shelters*, GATC Report MR-1190-50, (AD-413416), General American Transportation Corporation, MRD Division, Niles, IL, April 1963.

Charanian, T. R., and J. D. Zeff, *Experimental Evaluation of Environmental Control Systems for Closed Shelters*, GATC Report MRD 1242-2530 (AD-445002), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, July 1964.

Chester, C.V., "Preparing Underground Structures for Civil Defenses," *Underground Space* *6* (3), pp. 160-165 (November/December 1981).

Chester, C.V., "Incorporating Civil Defense Shelter Space in New Underground Construction," in *Underground Space Conference and Exposition*, CONF-810671-1, (a conference held June 8, 1981, in Kansas City, KS), 1981.

Chester, C.V., *Tests of the LUWA Blast Valve*, ORNL-TM-2796, Oak Ridge National Laboratory, Oak Ridge, TN, December 1969.

Chester, C.V., and D.W. Holladay, *A Preliminary Study of Reducing the Cost of Blast Shelter for Critical Workers*, ORNL-5958 (AD-A133542), prepared for Federal Emergency Management Agency by Oak Ridge, TN, October 1983.

Chester, C.V., H.B. Shapira, G.A. Cristy, M. Schweitzer, S.A. Carnes, and D. Torri-Safdie, *Hazard Mitigation Potential of Earth-Sheltered Residences*, ORNL-5957 (AD-A135367), Oak Ridge National Laboratory, Oak Ridge, TN, November 1983.

Chester, C.V., D. Torri-Safdie, G.A. Cristy, H.B. Shapira, and C. Taylor, "The Home As a Haven -- Drawings for a Blast Upgradable Hazard-Resistant Earth-Sheltered Residence" Journal of Civil Defense 17 (2), pp. 6-9 (April 1984).

Chester, C.V., D. Torri-Safdie, G.A. Cristy, C. Taylor, G.P. Zimmerman, "The Home as a Haven -- II; Drawings for Two More Blast-Upgradable Hazard-Resistant Earth Sheltered Residences," Journal of Civil Defense 18 (5), pp. 12-15 (October 1985).

Chester, C.V., and G.P. Zimmerman, "Civil Defense Implications of Biological Weapons - 1984," Journal of Civil Defense 17 (6), pp. 6-12 (December 1984).

Childers, H.M., C.A. Vansant, and D.F. Mokrauer, Protective Capabilities of the National Fallout Shelter System (Final Report), Vertex TR No. 68-2 (AD-680936), prepared for Office of Civil Defense by the Vertex Corporation, Kensington, MD, November 1968.

Childers, H.M., C.A. Vansant, and D.F. Mokrauer, Open Shelter Feasibility Study (Final Report), Vertex TR No. 68-1 (AD-688659), prepared for Office of Civil Defense by the Vertex Corporation, Kensington, MD, October 1968.

Chilton, A.B., Further Analysis of Gamma Ray Attenuation in Two-Legged Rectangular Ducts, NCEL-TN-412 (AD-256503), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, May 1961.

Chilton, A.B., Blast Pressure Leakage into Closed Structures Through Small Openings, Technical Study No. 23 (AD-224508), U.S. Department of the Navy, Bureau of Yards and Docks, Washington, DC, February 1958.

Chow, B.F., The Nutritional Value of OCD Rations (Final Report--Part II), AD-713018, prepared for Office of Civil Defense by John Hopkins University, Department of Biochemistry, Baltimore, MD, August 1969.

Christiansen, J. R., and W. K. Warner, Field Testing the Feasibility Report Using Residential Shelters as Group Shelters (Final Report), AD-774146, prepared for Defense Civil Preparedness Agency by Brigham Young University, by Department of Sociology, Provo, UT, January 1974.

Christiansen, J. R., W. K. Warner, and R. H. Blake, Field Testing Feasibility of Using Residential Shelters as Group Shelters--Appendix A: Colorado Springs Field Test Communication Package, AD-774147, prepared for Defense Civil Preparedness Agency, by

Brigham Young University Department of Sociology, Provo, UT, January 1974a.

Christiansen, J.R., W.K. Warner, and R.H. Blake, Field Testing the Feasibility of Using Residential Shelters as Group Shelters--Appendix B: Modified Colorado Springs Field Test Communication Package (Final Report), AD-774148, prepared for Defense Civil Preparedness Agency by Brigham Young University, Department of Sociology, Provo, UT, January 1974b.

Christiansen, W.J., Blast Effects on Miscellaneous Structures (Operation CASTLE, Project 3.5), WT-901, Defense Atomic Support Agency, Washington, DC, July 1955.

Clarke, E.T., J.F. Batter, Jr., and A.L. Kaplan, Measurement of Attenuation in Existing Structures of Radiation from Simulated Fallout, TO-B-59-4 (AD-276548), Technical Operations, Inc., Burlington, MA, April 1959.

Cohen, E. and A. Bottenhofer, Test of German Underground Personnel Shelters (Operation PLUMBBOB, Project 30.7), WT-1454, Ammann and Whitney, New York, NY, June 1962.

Cohen, E., and N. Dobbs, Test of French Underground Personnel Shelters (Operation PLUMBBOB, Project 30.6) WT-1453, Ammann and Whitney, New York, NY, June 1960.

Cohen, E., E. Laing, and A. Bottenhofer, Response of Dual-Purpose Reinforced-Concrete Mass Shelter (Operation PLUMBBOB, Project 30.2), WT-1449 (AD-A073525), Ammann and Whitney, New York, NY, September 1962.

Cohen, E., E. Laing, and A. Bottenhofer, Response of Protective Vaults to Blast Loading (Operation PLUMBBOB, Project 30.4), WT-1451 (AD-611258), Ammann and Whitney, New York, NY, May 1962.

Cohen, E., and S. Weissman, "Blast-Closure Systems," pp. 205-225 in Proceedings of the Symposium on Protective Structures for Civilian Populations (held April 19-23, 1965, in Washington, DC), AD-951921, National Academy of Sciences, Washington, DC, 1965.

Collins, J.D., R.D. Daniels, and K.B. Overbeck, Uncertainties in the Ground Shock Estimation Process, DNA-4769Z, prepared for Defense Nuclear Agency by J.H. Wiggins, Co., Redondo Beach, CA, August 1978.

Collins, R.A., The Investigation of Shelter Management and Control in Natural Disaster (Final Report), AIR-31200-12/72-FR (AD-759842), prepared for Defense Civil Preparedness Agency by American Institutes for Research, Coral Gables, FL, December 1972.

Collins, R.A., and E. Bend, Expansion of Research Data from Shelter Occupancy Exercises (Final Report), AIR-F26-8/68-FR (AD-676852), prepared for Office of Civil Defense by American Institutes for Research, Institute for Performance Technology, Pittsburg, PA, August 1968.

Collins, R.A. and E. Bend, Research Data from Shelter Occupancy Exercises (Final Report), AIR-D66-12/66-FR (AD-648870), prepared for Office of Civil Defense, by American Institutes for Research, Institute for Performance Technology, Pittsburgh, PA, December 1966.

Collins, R.A., and S.B. Mann, Model Large Individual Shelter Plans (Final Report), AIR-77804-7/71-FR (AD-732514), prepared for Office of Civil Defense, by American Institutes for Research, Pittsburgh, PA, July 1971.

Combe, M. A., D. B. Nelson, and J.C. Tomcala, Ventilation Tests of Fallout Shelter Spaces in New York City and Vicinity (Final Report), AD-631420, prepared for Office of Civil Defense by Guy B. Panero, Inc., New York, NY, February 1966.

The Committee for the Compilation of Materials on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki, Hiroshima and Nagasaki -- The Physical, Medical, and Social Effects of the Atomic Bombings (translated from Japanese by E.Ishikawa and D.L. Swain), published by Basic Books, Inc., New York, NY, 1981.

Condie, S. J., R. J. Goodwin, J. F. A. Seggar, and C.H. Kearny, Feasibility of Citizen Construction of Expedient Fallout Shelters (Final Report), ORNL-5368 (AD-A058051), Oak Ridge National Laboratory, Oak Ridge, TN, August 1978.

Condit, R.I., Area-Wide Shelter Systems, SRI Project MU-4536 (AD-635931), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, December 1965.

Condit, R.I., National Opportunities for Furthering Civil Defense Through Urban Renewal and Other New Construction (Final Report, Volume II), SRI Project No. IM-4075, prepared for Urban Renewal Administration and Norfolk Redevelopment and Housing Authority by Stanford Research Institute, Menlo Park, CA, November 1962a.

Condit, R.I., Suggested Long-Range Policy Toward New Construction for the National Shelter Program (Technical Report. No. 1), SRI Project No. IM-4075, prepared for Office of Civil Defense and Urban Renewal Administration by Stanford Research Institute, Menlo Park, CA, November 1962b.

Condit, R.I., Design Concepts for Adding 30 Psi Fallout Shelters to Occupied Buildings (Technical Report No. 3), SRI Project No. IM-4075, prepared for Norfolk Redevelopment and Housing Authority by Stanford Research Institute, Menlo Park, CA, November 1962c.

Condit, R.I., Special Civil Defense Facilities Essential to the Satisfactory Operation of Protective Shelters in Downtown Norfolk, Virginia (Technical Report No. 5), SRI Project IM-4075, prepared for Norfolk Redevelopment and Housing Authority by Stanford Research Institute, Menlo Park, CA, November 1962d.

Corsbie, R.L., AEC Communal Shelter Evaluation (Operation BUSTER, Project 9.1b), WT-360, U.S. Atomic Energy Commission, Washington, DC, March 1952.

Coulter, G.A., Blast Loading of Closure for Use on Shelters -- II, ARBRL-MR-038 (AD-A139632), U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, February 1984.

Coulter, G.A., Blast Loading of Closures for Use on Shelters, ARBRL-MR-03279 (AD-A130028), U.S. Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1983.

Coulter, G.A., Blast Loading of Wall Panels and Commercial Closures, AD-B063574, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, February 1982.

Coulter, G.A., Blast Loading of Construction Materials and Closure Designs, ARBRL-MR-02947 (AD-A077116), U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1979.

Coulter, G.A., Debris Hazard from Blast Loaded Plywood Sheet Closures, ARBRL-MR-02917 (AD-A071460), U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, May 1979.

Coulter, G.A., Translation and Impingement of Furniture Debris in a Model Apartment House Shelter, ARBRL-MR-02835 (AD-A056315), U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, May 1978.

Coulter, G.A., Blast Loading on Model Dummies in Two-Room Shelters, BRL-MR-2674 (AD-A031522), U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, September 1976.

Coulter, G.A., Blast Loading in Shelter Models -- Basement and Mine Shelters, BRL-MR-2476 (AD-A010322), U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, April 1975.

Coulter, G.A., Blast Loading of Objects in Basement Shelter Models, BRL-MR-2348 (AD-775456), U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, January 1974.

Coulter, G.A., Blast Loading in Existing Structures -- Basement Models, BRL-MR-2208 (AD-751769), U.S. Army Ballistic Research Laboratories, Terminal Ballistic Laboratory, Aberdeen Proving Ground, MD, August 1972.

Coulter, G.A., Air Shock Loading of Exterior Walls of Shelter Models, BRL-MR-2118 (AD-729775), Ballistic Research Laboratories, Aberdeen Proving Ground, MD, August 1971.

Coulter, G.A., Flow in Model Rooms Caused by Air Shock Waves, BRL-MR-2044 (AD-711855), U.S. Army Ballistic Research Laboratories Aberdeen Proving Ground, MD, July 1970.

Coulter, G.A., Air Shock and Flow in Model Rooms, BRL-MR-1987 (AD-693897), U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, June 1969.

Coulter, G.A., Attenuation of Peaked Air Shock Waves in Smooth Tunnels, BRL-M-1809, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, November 1966.

Crawford, R.E., C.J. Higgins, and E.H. Bultman, The Air Force Manual for Design and Analysis of Hardened Structures, AFWL-TR--74-102 (AD-B004152), prepared for Air Force Weapons Laboratory, Kirtland Air Force Base, NM, by Civil Nuclear Systems Corporation, Albuquerque, NM, October 1974.

Cristy, G. A., Blast Shelter for Critical Industry Workers (Final Report), ORNL-5022 (AD-A014626), Oak Ridge National Laboratory, Oak Ridge, TN, August 1975.

Cristy, G.A., Expedient Shelters Survey (Final Report), ORNL-4860 (AD-770138), Oak Ridge National Laboratory, Oak Ridge, TN, July 1973.

Cristy, G. A., Blast Shelter Potential in New Government Buildings (Final Report), ORNL-4849, Oak Ridge National Laboratory, Oak Ridge, TN, February 1973.

Cristy, G.A. (ed.), Technical Directives for the Construction of Private Air Raid Shelters and the 1971 Conception of the Swiss Civil Defense (TWP-1966, Swiss Federal Department of Justice and Police Office of Civil Defense - English Language Edition), ORNL-TR-2707, Oak Ridge National Laboratory, Oak Ridge, TN, 1973a.

Cristy, G.A., "Dual-Purpose Blast Shelters," pp. 77-81 in Annual Progress Report -- Civil Defense Research Project, March 1970-March 1971, ORNL-4679, Oak Ridge National Laboratory, Oak Ridge, TN, March 1972.

Cristy, G.A., Transportation Systems and Dual Purpose Blast Shelters (Final Report), ORNL-4675 (AD-735001), Oak Ridge National Laboratory, Oak Ridge, TN, October 1971.

Cristy, G.A., "Washington, DC, Subway," pp. 175-180 in Annual Progress Report -- Civil Defense Research Project, March 1967-March 1968, ORNL-4284 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, November 1968.

Cristy, G.A., "Dual-Use Shelter Systems," pp. 14-17 in Annual Progress Report -- Civil Defense Research Project, March 1968-March 1969, ORNL-4413 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, October 1968.

Cristy, G.A., "Washington, DC, Subway," pp. 285-298 in Annual Progress Report -- Civil Defense Research Project, March 1966-March 1967, ORNL-4184 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, December 1967a.

Cristy, G.A., "Blast Shelter Entry Systems," pp. 299-321 in Annual Progress Report -- Civil Defense Research Project, March 1966-March 1967, ORNL-4184 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, December 1967b.

Cristy, G.A., "Protected Cities," pp. 322-348 in Annual Progress Report -- Civil Defense Research Project, March 1966-March 1967, ORNL-4184 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, December 1967c.

Cristy, G.A., and C.H. Kearny, Expedient Shelter Handbook (Final Report), ORNL-4941 (AD-787483), Oak Ridge National Laboratory, Oak Ridge, TN, August 1974.

Cristy, G.A., and C.J. Williams, "Protected City Studies," pp. 166-186 in Annual Progress Report -- Civil Defense Research Project, March 1965 - March 1966, ORNL-TM-1531 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, November 1966.

Criswell, M.E., Design and Testing of a Blast-Resistant Reinforced Concrete Slab System, Technical Report N-72-10 (AD-755096), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, November 1972.

Criswell, M.E., Strength and Behavior or Reinforced Concrete Slab-Column Connections Subjected to Static and Dynamic Loadings, TR-70-1 (AD-717308), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, December 1970.

Crowley, J.W., R.M. Hogue, H.J. Avise, E.H. Smith, and W.G. Hiner, Development of Analytical Relationships and Criteria for Blast and Fire Vulnerability of Fallout Shelter Occupants (Final Report), AD-842356, prepared for Office of Civil Defense by System Science, Inc., Bethesda, MD, October 1968.

Cummins, R.S., Jr., Blast Door Tests for the Federal Republic of Germany (Final Report), Miscellaneous Paper N-76-13 (AD-B014368), prepared for Defense Nuclear Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, September 1976.

Curione, C., Construction Resources Availability in Support of Blast Shelter Programs (Final Report), SRI Project MU-6300-040, (AD-676221), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, May 1968.

Curione, C., Cost Trends of Mass Production as Applied to 5-10 PSI Shelter (Final Report), SRI Project MU-4949-022 (AD-653669), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, February 1967.

Curione, C., Cost Guidance for Protective Construction, Technical Study No. 24 (AD-224509), U.S. Department of the Navy, Bureau of Yards and Docks, Washington, DC, August 1958.

DaDeppo, D.A., and J.F. Werner, The Influence of Mechanical Shielding on the Response of a Buried Cylinder, NBy-32199 (AD-277436), prepared for U.S. Naval Civil Engineering Laboratory by the University of Arizona, Engineering Research Laboratory, Tucson, AZ, February 1962.

Daniels, R.D., An Analysis of Uncertainties in the Ground Shock Estimation Process, DNA-5213F, prepared for Defense Nuclear Agency by J.H. Wiggins, Co., Inc., Redondo Beach, CA, June 1979.

"Dateline Nuclear Fallout Shelter: Mark Two With Access Chamber," Protect and Survive Monthly (United Kingdom) 1 (3), pp. 20-21 (March 1981).

Davies, I., SES 100 Ton TNT Trial - Suffield, Alberta, August 1961; Performance Test on Model Garage-Shelter Roof System, AWRE Report No. E2/63, United Kingdom Atomic Energy Authority, Atomic Weapons Research Establishment, Aldermaston, Berkshire, March 1963.

Davis, L.L., A Summary of Ground Motion Prediction Procedures and Equations, NVO-1163-49 (Revision 1), prepared for U.S. Atomic Energy Commission by Roland F. Beers, Inc., Alexandria, VA, March 1965.

Davis, L.W., W.L. Baker, and D.L. Summers, Analysis of Japanese Nuclear Casualty Data, DC-FR-1045, prepared for U.S. Atomic Energy Commission by Dikewood Corporation, Albuquerque, NM, April 1966a.

Davis, L.W., W.L. Baker, and D.L. Summers, Analysis of Japanese Nuclear Casualty Data, DC-FR-1054, prepared for Office of Civil Defense by Dikewood Corporation, Albuquerque, NM, April 1966b.

Davis, N.J., Jr., Protection Afforded by Field Fortifications Against Nuclear Weapons Effects, AERDL-1557-TR (AD-860811), U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, VA, December 1958.

Davis, T.P., N.D. Miller, T.S. Ely, J.A. Basso, and H.E. Pearse, The Scattering of Thermal Radiation into Open Underground Shelters, CEX-58.2, University of Rochester, Rochester, NY, May 1959.

Defense Civil Preparedness Agency, Architectural Design Techniques for Fallout Protection and Energy Conservation, TR-86, Washington, DC, September 1978.

Defense Civil Preparedness Agency, Shelter Environmental Support Systems, TR-20 (Vol. I), Washington, DC, May 1978.

Defense Civil Preparedness Agency, Buildings with Protection Against the Effects of Nuclear Weapons; Design Case Study 12 -- State Defense Building in Topeka, Kansas, DCS-12, Washington, DC, April 1978.

Defense Civil Preparedness Agency, Shelter Design and Analysis -- Fallout Radiation Shielding, TR-20 (Vol. I), Washington, DC, February 1978 (includes Change 1).

Defense Civil Preparedness Agency, Building Design for Radiation Shielding and Thermal Efficiency, TR-85, Washington, DC, December 1977.

Defense Civil Preparedness Agency, Wind Resistant Design Concepts for Residences, TR-83, Washington, DC, November 1976.

Defense Civil Preparedness Agency, Shelter Design and Analysis, Protection Factor Estimator with Instructions, TR-20 (Vol. II), Washington, DC, February 1976.

Defense Civil Preparedness Agency, High Risk Areas, TR-82, Washington, DC, April 1975.

Defense Civil Preparedness Agency, Schools in Kansas with Tornado Protection, TR-79, Washington, DC, July 1973.

Defense Civil Preparedness Agency, Cost Benefit in Shelters, TR-69, Washington, DC, November 1972a.

Defense Civil Preparedness Agency, Technical Standards for Fallout Shelter Designs, TM-72-1, Washington, DC, November 1972b.

Defense Civil Preparedness Agency, Shelters in New Apartments, TR-74, Washington, DC, August 1972.

Defense Documentation Center, Civil Defense Systems: Shelters -- A DDC Bibliography, DDC-TAS-72-14-I (AD-740960), Alexandria, VA, April 1972.

Defense Logistics Agency, Logistics Study - Shelter Stockage, AD-A081377, prepared for the Federal Emergency Management Agency by the Defense Logistics Agency, Richmond, VA, November 1979.

De Leuw, Cather and Company, Deep Excavation Techniques for Shelters in Urban Areas (Preliminary Planning and Cost Data), AD-411786, prepared for Office of Civil Defense by De Leuw, Catherand Company, Chicago, IL, July 1963.

Dembo, M.M. and D.B. Baldwin, Design and Evaluation: 480-Person Austere Community Fallout Shelter (Final Report), PSDC-TR-12 (AD-671637), prepared for Office of Civil Defense by Protective Structures Development Center, Fort Belvoir, VA, June 1967.

Dembo, M.M., and H.C. Lamb, Family Shelter Earth-Covered Wood A-Frame, PSDC-TR-10, (AD-A953107), prepared for Office of Civil Defense by Protective Structures Development Center, Fort Belvoir,VA, October 1965.

Dennis, R., C.E. Billings, and L. Silverman, Blast Effects on an Air-Cleaning System (Operation PLUMBBOB, Project 34.4), WT-1475, Harvard University, Air Cleaning Laboratory, Boston, MA, April 1962.

Denton, D.R., A Dynamic Ultimate Strength Study of Simply Supported Two-Way Reinforced Concrete Slabs (Final Report), Technical Report No. 1-789 (AD-658749), prepared for Office of Civil Defense by U.S. Army Waterways Experiment Station, Vicksburg, MS, July 1967.

Des Rosiers, P.E., Human Waste Studies in an Occupied Civil Defense Shelter (Division Report), AD-671703, U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, VA, June 1965.

Des Rosiers, P.E., Investigation of Low-Cost Sanitation Systems, USAERDL Project 8A72-04-001-29 (AD-403823), U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, VA, November 1962.

Devaney, J.F., The Use of Systems Techniques in Civil Defense (Final Report), URS-691 (AD-712314), prepared for Office of Civil Defense through Stanford Research Institute by URS Research Company, San Mateo, CA, May 1970.

Devaney, J.F., Estimated Cost of Shelter (A Research Memorandum), Office of Civil Defense, Washington, DC, May 1964.

Devaney, J.F., Shelter, OCDM-SA-61-12 (AD-276518), Executive Office of the President, Office of Civil and Defense Mobilization, Operations Research Office, Washington, DC, June 1961.

Dickey, E., Passport to Survival; Four Foods and More to Use and Store, published by Bookcraft Publishers, Inc., (1848 West 2300 South), Salt Lake City, UT, 1969.

Donovan, L.K., and A.B. Chilton, Dose Attenuation Factors for Concrete Slab Shields Covered with Fallout as a Function of Time after Fission, NCEL-TR-137, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, June 1961.

Dorris, A.F., Response of Horizontally Oriented Buried Cylinders to Static and Dynamic Loading, TR-1-682 (AD-621340), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, July 1965.

Dresner, L., "Peak Overpressure at the Foot of a Vertical Wall Facing an Air Blast," Journal of Applied Physics 40 (4), pp. 1945-1949 (March 15, 1969).

Ducar, G.J., R.J. Baschiere, and G. Engholm, Analysis of Ventilation Air Distribution Requirements for Survival Shelters (Phase 1), GATC-IR-MRD-1195-70-1 (AD-450921), prepared for Office of

Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, April 1963.

Duff, R.E., and R.N. Hollyer, Jr., The Diffraction of Shock Waves Through Obstacles with Various Openings in their Front and Back Surfaces, Report 50-3 and NP-1886, prepared for U.S. Navy Department by University of Michigan, Engineering Research Institute, Ann Arbor, MI, November 1950.

Earp, K.F., Deaths from Fire in Large Scale Air Attack -- with special reference to the Hamburg Fire Storm, CD/SA-28, Home Office, Scientific Advisor's Branch, Whitehall, Great Britain, April 1953.

Eberle M. Smith Associates, Inc., Professional Guide -- Incorporation of Shelter into Schools, Contract No. OCD-OS-62-47, prepared for Office of Civil Defense by Eberle M. Smith Associates, Inc., Detroit, MI, June 1962.

Edmunds, J.E., Structural Debris and Building Damage Prediction Methods, URS-686-5 (AD-857886), prepared for Office of Civil Defense by URS Research Co., Burlingame, CA, June 1968.

Egorov, P.T., I.A. Shlyakhov, and N.I. Alabin, Civil Defense, Moscow -- 1970 (Translated from Russian by Scientific Translation Service, Ann Arbor, MI; edited by J.S. Gailar, C.H. Kearny, and C.V. Chester) ORNL-TR-2793 (AD-773427), Oak Ridge National Laboratory, Oak Ridge, TN, December 1973.

Eisenhauer, C., An Engineering Method for Calculating Protection Afforded by Structures Against Fallout Radiation (a National Bureau of Standards Monograph), NBS-Mono-76, U.S. Department of Commerce, National Bureau of Standards, Washington, DC, July 1964.

Ellis, R.C., Missouri Underground Shelter Space -- A Fallout Shelter Survey of Mines and Caves in Missouri, Contract CDM-OS--61-40, prepared for Office of Civil Defense by Missouri Civil Defense Agency, Jefferson City, MO, January 1962.

Emergency Measures Organization (Canada), Plans and Specifications for Family Blast Shelters (30 psi) (Supplement to Blueprint for Survival No. 6), Cat. No. S82-662/3, Ottawa, Canada, 1962a.

Emergency Measures Organization (Canada), Simpler Shelters (Pamphlet), Cat. No. S82-463, Ottawa, Canada, 1962b.

Emergency Measures Organization (Canada), Your Basement Fallout Shelter -- Blueprint for Survival No. 1, Cat. No. S83-1/1, Ottawa, Canada, 1961.

Emergency Measures Organization (Canada), Canada EMO Above Ground Fallout Shelter, Ottawa, Canada, no date.

Everetts, J., Jr., D.R. Witt, and E.R. McLaughlin, The Feasibility of Augmenting Below-Grade Shelter Habitability with Conditioned Air (Final Report), AD-701132, prepared for Office of Civil Defense by Pennsylvania State University, Department of Architectural Engineering and Institute for Building Research, University Park, PA, January 1970.

Fabuss, B.M., and A.S. Borsanyi, Self-Contained Generator for Shelter Use, MRB-6024-F, prepared for Office of Civil Defense by Monsanto Research Corporation, Everett, MA, October 1964.

Fairhurst, C., "Going Under to Stay on Top," Underground Space 1 (2), pp. 71-86 (July/August 1976).

Federal Emergency Management Agency, FEMA Publications Catalog, FEMA-20, U.S. Government Printing Office, Washington, DC, April 1985.

Federal Emergency Management Agency, Protective Construction -- Nuclear Blast Resistant Design, TR-20 (Vol. IV), Washington, DC, March 1985.

Federal Emergency Management Agency, Protective Construction, TR-39, Washington, DC, January 1985.

Federal Emergency Management Agency, In Time of Emergency -- A Citizen's Handbook, H-14, Washington, DC, February 1984.

Federal Emergency Management Agency, Soviet Civil Defense, FEMA-52, Washington, DC, December 1983.

Federal Emergency Management Agency, Belowground Home Fallout Shelter, H-12-1, Washington, DC, November 1983a.

Federal Emergency Management Agency, Aboveground Home Fallout Shelter, H-12-2, Washington, DC, November 1983b.

Federal Emergency Management Agency, Home Blast Shelter, H-12-3, Washington, DC, November 1983c.

Federal Emergency Management Agency, What You Should Know About Nuclear Preparedness, L-138, Washington, DC, November 1983d.

Federal Emergency Management Agency, Radiation Safety in Shelters, CPG-2-6.4, Washington, DC, September 1983.

Federal Emergency Management Agency, Tornado Protection -- Selecting and Designing Safe Areas in Buildings, TR-83B, Washington, DC, October 1982.

Federal Emergency Management Agency, Increasing Blast and Fire Resistance in Buildings: Design Techniques for Combined Nuclear Weapon Effects, TR-62, Washington, DC, August 1982.

Federal Emergency Management Agency, How to Use Your Radiological Instruments (Survey Meter and Dosimeter) To Find the Best Shelter and To Minimize Your Exposure to Radiation, MP-72, Washington, DC, July 1982.

Federal Emergency Management Agency, FEMA Attack Environment Manual (Civil Preparedness Guide; Chapter 1: Introduction to Nuclear Emergency Operations), CPG-2-1A1, Washington, DC, May 1982a.

Federal Emergency Management Agency, FEMA Attack Environment Manual (Civil Preparedness Guide; Chapter 2: What the Planner Needs to Know About Blast and Shock), CPG-2-1A2, Washington, DC, May 1982b.

Federal Emergency Management Agency, FEMA Attack Environment Manual (Civil Preparedness Guide; Chapter 3: What the Planner Needs to Know About Fire Ignition and Spread), CPG-2-1A3, Washington, DC, May 1982c.

Federal Emergency Management Agency, FEMA Attack Environment Manual (Civil Preparedness Guide; Chapter 4: What the Planner Needs to Know About Electromagnetic Pulse), CPG-2-1A4, Washington, DC, May 1982d.

Federal Emergency Management Agency, National Shelter Survey Instructions, TR-84, Washington, DC, May 1982e.

Federal Emergency Management Agency, Fast Start to Fallout Shelter Analysis, HS-7 (Part 3), Washington, DC, February 1981.

Federal Emergency Management Agency, FEMA Attack Environment Manual (Civil Preparedness Guide; Chapter 5: What the Planner Needs to Know About Initial Nuclear Radiation), CPG-2-1A5, Washington, DC, October 1980.

Federal Emergency Management Agency, Mass Thickness Manual for Walls, Floors, and Roofs, TR-86, Washington, DC, September 1980.

Federal Emergency Management Agency, Home Fallout Shelter: Modified Ceiling Shelter -- Basement Location (Plan A), H-12-A, Washington, DC, April 1980a.

Federal Emergency Management Agency, Home Fallout Shelter: Modified Ceiling Shelter -- Basement Location (Plan B), H-12-B, Washington, DC, May 1980b.

Federal Emergency Management Agency, Home Fallout Shelter: Concrete Block Shelter -- Basement Location (Plan C), H-12-C, Washington, DC, May 1980c.

Federal Emergency Management Agency, Home Fallout Shelter: Snack Bar -- Basement Location (Plan D), H-12-D, Washington, DC, April 1980d.

Federal Emergency Management Agency, Home Fallout Shelter: Tilt-Up Storage Unit Shelter -- Basement Location (Plan E), H-12-E, Washington, DC, April 1980e.

Federal Emergency Management Agency, Home Fallout Shelter: Lean-to Shelter -- Basement Location (Plan F), H-12-F, Washington, DC, April 1980f.

Federal Emergency Management Agency, Decontamination Considerations for Architects and Engineers, TR-71, Washington, DC, April 1980g.

Federal Emergency Management Agency, Shelter Analysis for Nuclear Defense (SAND), TR-55, Washington, DC, January 1980a.

Federal Emergency Management Agency, Interim Guidelines for Building Occupant Protection from Tornadoes and Extreme Winds, TR-83A, Washington, DC, January 1980b.

Federal Emergency Management Agency, Standards for Fallout Shelters: Public Fallout Shelters and Shelters in Hospitals, TR-87, Washington, DC, September 1979.

Federal Emergency Management Agency, FEMA Attack Environment Manual (Civil Preparedness Guide; Chapter 6: What the Planner Needs to Know About Fallout), CPG-2-1A6, Washington, DC, June 1973a.

Federal Emergency Management Agency, FEMA Attack Environment Manual (Civil Preparedness Guide; Chapter 7: What the Planner Needs to Know About the Shelter Environment), CPG-2-1A7, Washington, DC, June 1973b.

Federal Emergency Management Agency, FEMA Attack Environment Manual (Civil Preparedness Guide; Chapter 8: What the Planner Needs to Know About the Post-Shelter Environment), CPG-2-1A8, Washington, DC, June 1973c.

Federal Emergency Management Agency, FEMA Attack Environment Manual (Civil Preparedness Guide; Chapter 9: Application to Emergency Operations Planning), CPG-2-1A9, Washington, DC, June 1973d.

Federal Office of Civil Defense (Swiss), Swiss Civil Defense -- Figures, Facts and Data, Berne, Switzerland, 1985.

Federal Office of Civil Defense (Swiss), Shelters for Persons, Berne, Switzerland, July 1983.

Fedorkiw, J.P., and M.A. Sozen, A Lumped-Parameter Model to Simulate the Response of Reinforced Concrete Frames with Filler Walls (Civil Engineering Studies), Structural Research Series No. 338 (AD-684942), prepared for Office of Civil Defense by University of Illinois, Urbana, IL, June 1968.

Feinstein, D.I., W.F. Heugel, M.L. Kardatzke, and A. Weinstock, Personnel Casualty Study (Final Report), IITRI Project J6067 (AD-842573), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, July 1968.

Feinstein, D.I., and J.R. Wingfield, A Methodology for Forecasting the Distribution of Basement Plan Areas in Future Construction (Final Report), IITRI Project J6144J04 (AD-872755), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, July 1970.

Ferlic, K.P., Fallout: Its Characteristics and Management, AFRRI-TR-83-5 (AD-A140011), Armed Forces Radiobiology Research Institute, Bethesda, MD, December 1983.

Ferritto, J.M., Cost-Optimization Study of Shelter Entrance Structures to Resist Blast Overpressure and Radiation Effects, NCEL-TR-737 (AD-732360), Armed Forces Radiobiology Research Institute, Bethesda, MD, September 1971a.

Ferritto, J.M., Design Procedures for Shelter Entrance Structures to Resist Blast Overpressure and Radiation Effects, NCEL-TR-736 (AD-732359), Naval Civil Engineering Laboratory, Port Hueneme, CA, September 1971b.

Ferritto, J.M., Use of an Aerodynamic Obstruction to Shield a Blast Door -- Results of an Experimental Model Test, NCEL-TR-739 (AD-732362), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, October 1971.

Fiorato, A.E., M.A. Sozen, and W.L. Gamble, An Investigation of the Interaction of Reinforced Concrete Frames with Masonry Filler Walls, UILU-ENG-70-100 (AD-719267), prepared for Office of Civil Defense by University of Illinois, Urbana, IL, November 1970.

Finlayson, F., L.E. Fugelso, and Y.S. Shulman, Design Procedures for Shock Isolation Systems of Underground Protective Structures; Volume II: Structure Interior Motions Due to Directly Transmitted Ground Shock, RTD-TDR-63-3096 (Vol. II), (AD-627597), prepared for U.S. Air Force Weapons Laboratory by General American Transportation Corporation, Niles, IL, December 1965.

Fischer, M.J., E.Z. Faby, R.T. Robinson, and F.W. Leonard, Methods and Procedures to Specify Key-Worker Blast Shelter (KWBS) Location and Requirements (Volume 1, Main Report), EER-TR-009-84 (AD-A142454), prepared for the Federal Emergency Management Agency by Engineering and Economics Research, Inc., Vienna, VA, May 1984.

FitzSimons, N., Evaluation of Industrial Doors Subjected to Blast Loading (Operation PLUMBBOB, Project 31.4), ITR-1459, Federal Civil Defense Administration, Washington, DC, February 1958.

FitzSimons, N., Evaluation of FCDA Family Shelter, Mark I, for Protection Against Nuclear Weapons (Operation PLUMBBOB, Project 30.3), ITR-1450, Federal Civil Defense Administration, Washington, DC, August 1957.

Flanigan, F.M. and J.O. Gonzalez, Jr., Moisture in Survival Shelters (Final Report), AD-600437, prepared for Office of Civil Defense by University of Florida, Engineering and Industrial Experiment Station, Gainesville, FL, April 1964.

Flanigan, F.M., C.A. Morrison, and P.L. Bass, Final Report Summarizing Simulated Occupancy Shelter Tests Conducted During the Period of July 5, 1962 through November 5, 1964, AD-648492, prepared for Office of Civil Defense by Florida University of Engineering and Industrial Experiment Station, Gainesville, FL, December 1966.

Flathau, W.J., and J.P. Balsara, "Soil-Structure Interaction -- An Overview," pp. 13-33 in Earth Covered Buildings: Technical Notes (Volume I from a conference titled: Alternatives in Habitat: the Use of Earth Covered Settlements, May 17-19, 1978, in Fort Worth, TX), CONF-7805138-P1 published by the U.S. Department of Energy, Washington, DC, 1978.

Flathau, W.J., R.A. Breckenridge, and C.K. Wiehle, Blast Loading and Response of Underground Concrete-Arch Protective Structures (Operation PLUMBBOB, Project 3.1), WT-1420 (AD-B001855), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, and U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, June 1959.

Flathau, W.J., R.A. Sager, and F.A. Luzi, Design and Analysis of Underground Reinforced-Concrete Arches, AEWES-TR-2-590 (AD--274727), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, January 1962.

Flory R.A., DISTANT RUNNER Results (A 5 Event High Explosive Test Series Involving U.S. Air Force 3rd. Generation Aircraft Shelters), AD-P000507, Defense Nuclear Agency, Washington, DC, 1982.

Flynn, A.P., F.C.D.A. Family Shelter Evaluation (Operation BUSTER, Project 9.1a), WT-359, Federal Civil Defense Administration, Washington, DC, March 1952.

Flynn, R.M., Group Shelter Investigation, Office of Civil Defense Research Project No. 1702 (AD-400235), U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, VA, October 1962.

Forrestal, M. J., Protection Against High Blast Overpressure and Ground Shock (Final Report), GARD-MR-1188 (AD-401108), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, February 1963.

Fowler, T.R., and C.H. Dorn, Gamma Ray Attenuation in a 12-Inch-Diameter Round Concrete Duct, NCEL-TN-465 (AD-289349), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, November 1962.

Franke, H., and J. Schultz, "Shelters and Their Ventilation," AEGIS International (Switzerland) 2 (2), pp. 4-11 (April/May 1983).

Franz, K.B., and C.H. Kearny, Maintaining Nutritional Adequacy during a Prolonged Food Crisis, ORNL-5352, Oak Ridge National Laboratory, Oak Ridge, TN, August 1979.

French, R.L., and L.G. Mooney, Initial Radiation Exposure from Nuclear Weapons (Interim Report), RRA-T7201 (AD-745906), prepared for Office of Civil Defense by Radiation Research Associates, Inc., Fort Worth, TX, July 1972.

French, R.L., and L. Olmedo, Ground Roughness Calculations for Fallout Gamma Rays (Final Report), RRA-T61 (AD-637427), prepared for Office of Civil Defense by Radiation Research Associates, Inc., Fort Worth, TX, June 1966.

French, R.L., J.H. Price, and K.W. Tompkins, Ground Roughness Effects on Fallout Shielding (Final Report), RRA-T81 (AD-671902), prepared for Office of Civil Defense by Radiation Research Associates, Inc., Fort Worth, TX, January 1968.

French, R.L., J.H. Price, and K.W. Tompkins, An Analysis of the Performance of Enclosure Shields in a Real Fallout Field (Final Report), RRA-T55 (AD-637426), prepared for Office of Civil Defense by Radiation Research Associates, Inc., Fort Worth, TX, December 1965.

Gabrielsen, B.L., G.J. Cuzner, J. Hendricks, and T.C. Zsutty, The Analysis of the Effects of Frame Response on Basement Shelters in Tall Buildings (Final Report), SSI-8142-6 (AD-A121609), prepared for Federal Emergency Management Agency by Scientific Service Inc., Redwood City, CA, October 1982.

Gabrielsen, B.L., G.J. Cuzner, and R. Lindskog, Blast Upgrading of Existing Structures (Final Report), SSI-7719-4 (AD-A066998), prepared for Defense Civil Preparedness Agency by Scientific Service Inc., Redwood City, CA, January 1979.

Gabrielsen, B.L., R.S. Tansley, and G. Cuzner, Upgrading of Existing Structures -- Phase II (Final Report), SSI-7910-5 (AD-A086738), prepared for Federal Emergency Management Agency by Scientific Service Inc., Redwood City, CA, June 1980.

Gabrielsen, B., and C. Wilton, Shock Tunnel Tests of Arched Wall Panels, URS-7030-19 (AD-A066682), prepared for Defense Civil Preparedness Agency by URS Research Co., San Mateo, CA, December 1974.

Gabrielsen, B.L., C. Wilton, and K. Kaplan, Response of Arching Walls and Debris from Interior Walls Caused by Blast Loading, URS-7030-23 (AD-A014957), prepared for the Defense Civil Preparedness Agency by URS Research Company, San Mateo, CA, February 1975.

Gailar, J.S., W.H. Baldry, and A.S. Klein, Indexes to 708 Unclassified Documents on Civil Defense, ORNL-CD-8, Oak Ridge National Laboratory, Oak Ridge, TN, June 1970.

Gant, K.S., and C.M. Haaland, "Community Shelters for Protection from Radioactive Fallout: Availability and Patterns for Probable Use," Health Physics 37 (2), pp. 221-230 (August 1979).

Gasten, B.R., Consideration of Initial Nuclear Radiation in an Attack on a Civilian Population (Final Report), SRI Project 6680 (AD-A097732), prepared for National Bureau of Standards by SRI International, Menlo Park, CA, March 1980.

Gates, J.W., and R.M. Schwaner, Low-Cost Sleeping Facility (Final Report), Civil Defense Project No. 1310 (AD-425924), Quartermaster Research and Engineering Center, Natick, MA, October 1962.

General Electric Company, Improvised Power Supplies (Final Report), AD-445845, prepared for Office of Civil Defense by General Electric Company, Military Communications Department, Syracuse, NY, June 1964.

General Electric Company - TEMPO, Proceedings of the DICE THROW Symposium 21-23 June 1977 (Volume 1), DNA-4377P-1, prepared for Defense Nuclear Agency by General Electric Company-TEMPO, Santa Barbara, CA, July 1977a.

General Electric Company - TEMPO, Proceedings of the DICE THROW Symposium 21-23 June 1977 (Volume 2), DNA-4377P-2, prepared for Defense Nuclear Agency by General Electric Company-TEMPO, Santa Barbara, CA, July 1977b.

General Electric Company - TEMPO, Proceedings of the DICE THROW Symposium 21-23 June 1977 (Volume 3), DNA-4377P-3, prepared for Defense Nuclear Agency, Santa Barbara, CA, July 1977c.

General Electric Company - TEMPO, Proceedings of the MIXED COMPANY/MIDDLE GUST Results Meeting 13-15 March 1973 (Volume I-Sessions 1, 2A and 3A), prepared for Defense Nuclear Agency by General Electric Company-TEMPO, Santa Barbara, CA, May 1973a.

General Electric Company - TEMPO, Proceedings of the MIXED COMPANY /MIDDLE GUST Results Meetings 13-15 March 1973 (Volume II--Sessions 2B and 2C), prepared for Defense Nuclear Agency by General Electric Company-TEMPO, Santa Barbara, CA, May 1973b.

General Electric Company - TEMPO, Symposium Proceedings: OPERATION SNOWBALL; Volume I (held January 19-21, 1965, in Albuquerque, New Mexico), DASA-1642-1, prepared for Defense Atomic Support Agency by General Electric Company - TEMPO, Santa Barbara, CA, August 1965.

Getchell, J.V., and S.A. Kiger, Vulnerability of Shallow-Buried Flat-Roof Structures; Foam HEST 3 and 6, Technical Report

SL-80-7 (Report 4), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, December 1981.

Getchell, J.V., and S.A. Kiger, Vulnerability of Shallow-Buried Flat-Roof Structures; Foam HEST 5, Technical Report SL-80-7 (Report 3), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, February 1981.

Getchell, J.V., and S.A. Kiger, Vulnerability of Shallow-Buried Flat-Roof Structures; Foam HEST 4, Technical Report SL-80-7 (Report 2), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, October 1980.

Girolami, A.G., M.A. Sozen, W.L. Gamble, and H. Flug, 1. Flexural Strength of Reinforced Concrete Slabs with Externally Applied In-Plane Forces. 2. Strength of Slabs Subjected to Multiaxial Bending and Compression, UILU-ENG-70-105 (AD-719266) prepared for Office of Civil Engineering Department, Urbana, IL, October 1970.

Glasstone, S., and P.J. Dolan (eds.), The Effects of Nuclear Weapons -- 1977 (Third Edition), published by the U.S. Department Defense and the U.S. Department of Energy, 1977 (Available as Stock No. 008-046-00093-0 from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402).

Godfrey, L., "A Shoppers Guide to Nuclear Survival," New Scientist 87 (1209), pp. 274-278 (July 24, 1980).

Godfrey, R.S., (editor-in-chief), Building Construction Cost Data -- 1985 (43rd. Annual Edition), published by Robert Snow Means Company, Inc., Kingston, MA, 1984.

Goen, R.L., R.M. Rodden, and D.W. Goodrich, Critical Review of Cost-Effectiveness of Blast Shelters -- Phase II (Final Report), SRI Project No. MU-4949-230 (AD-839266), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, April 1968.

Goen, R.L., J.W. Ryan, A.C. Kamradt, S. Baum, and M. Radovic, Parametric Study of Shelter Costs, (SRI Project MU-4536), TN-OAP-21, prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, December 1966.

Goldbeck, R.A., and P.H. Newman, Habitability Test of the NRDL 100-Man Shelter, AIR-3158-60-FR-22 (AD-285474), prepared for Office of Civil and Defense Mobilization by American Institutes for Research, Pittsburgh, PA, February 1960.

Goldsmith, A., Experimental Evaluation of Simulated Heat and Moisture Loads in Shelters, AD-632219, prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, December 1965.

Goodale, T., An Attempt to Explore the Effect of High Blast Overpressure on the Persistence of Smouldering Combustion in Debris (Summary Report), URS-7030-6 (AD-740820), prepared for Office of Civil Defense by URS Research Company, San Mateo, CA, December 1971a.

Goodale, T., The Ignition Hazard to Urban Interiors During Nuclear Attack Due to Burning Curtain Fragments Transported by Blast (Summary Report), URS-7030-5 (AD-740821), prepared for Office of Civil Defense by URS Research Company, San Mateo, CA, December 1971b.

Goodrich, D.W., Utilization of Existing Shelter in Metropolitan Areas, SRI-RM-OAP-12, Stanford Research Institute, Menlo Park, CA, February 1965.

Gorecki, E. W., and A. G. Jago, Collapsible Water Container Kit, GARD Final Report 1478 (AD-722242), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, January 1971.

Goure, L., The Soviet Civil Defense Shelter Program (Special Report Series), published by University of Miami, Center for Advanced International Studies, Coral Gables, FL, 1981.

Goure, L., Shelters in Soviet War Survival Strategy, AD-A053250, prepared for Defense Civil Preparedness Agency by University of Miami, Center for Advanced International Studies, Coral Gables, FL, February 1978.

Goure, L., The Soviet Civil Defense Shelter Program, AD-A039526, prepared for Defense Civil Preparedness Agency by University of Miami, Center for Advanced International Studies, Coral Gables, FL, May 1977.

Granzow, K.D., and D.L. Summers, A Computer Program for Calculating Shelter Hardness and Cost for Uniform Survival Probability, DC-TN-1039-3, prepared for Office of Civil Defense by Dikewood Corporation, Albuquerque, NM, December 1964.

Granzow, K.D., D.L. Summers, and A.R. Bliss, A Computer Program for Finding the Order of Expenditure on Blast Shelters that Maximizes Additional Survivors per Dollar, DC-TN-1039-10, prepared for Office of Civil Defense by Dikewood Corporation, Albuquerque, NM, June 1965.

Granzow, K.D., D.L. Summers, and A. R. Bliss A Computer Program for Calculating the Expected Cost Per Survivor for a Uniform Shelter Design Overpresure Policy, DC-TN-1039-7, prepared for the Office of Civil Defense by Dikewood Corporation, Albuquerque, NM, January 1965.

Graves-Hill and Associates, A Model Building Code Article on Fallout Shelter with Recommendations for Inclusion of Requirements for Fallout Shelter Construction in Four National Model Building Codes, prepared for Office of Civil Defense under the auspices of the American Institute of Architects by Graves-Hill and Associates, Lexington, KY, October 1965.

Green, D.W., Attenuation of Gamma Radiation in a Two-Legged 11-Inch Rectangular Duct, NCEL-TR-195, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, May 1962.

Grimm, B.T., E.S. Pearsall, and S.A. Pratt, A Study of Active and Passive Systems for the Defense of Population Centers (Volume I), S-388-1 and IDA Log No. HQ71-12178 (AD-743537), Institute for Defense Analyses, Arlington, VA, September 1971a.

Grimm, B.T., E.S. Pearsall, and S.A. Pratt, A Study of Active and Passive Systems for the Defense of Urban Population Centers (Volume II: The Model), S-388-2 (AD-743538), prepared for Office of Civil Defense by Institute for Defense Analyses, Arlington, VA, September 1971b.

Grimm, B.T., E.S. Pearsall, and S.A. Pratt, A Study of Active and Passive Systems for the Defense of Urban Population Centers (Volume I: The Results), S-388-3 (AD-743539), prepared for Office of Civil Defense by Institute for Defense Analyses, Arlington, VA, September 1971c.

Grimm, B.T., E.S. Pearsall, and S.A. Pratt, A Study of Active and Passive Systems for the Defense of Urban Population Centers (Volume IV: The Computer Program), S-388-4 (AD-743540), prepared for Office of Civil Defense by Institute for Defense Analyses, Arlington, VA, September 1971d.

Guice, L.K., and S.A. Kiger, Elastic-Plastic Response Charts for Nuclear Overpressures, Miscellaneous Paper No. SL-84-7 (AD-A144111), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, June 1984.

Guice, L.K., and T.R. Slawson, Static and Dynamic Slab Tests Conducted at WES: FY 1978-1984, Technical Report SL-86-1, prepared for Defense Nuclear Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, February 1986.

Guy B. Panero, Inc., Cost Effectiveness of Water Wells (Final Report), AD-447991, New York, NY, September 1974.

Guy B. Panero, Inc., Ventilation Tests Performed on Fallout Shelter Spaces in New York City and Vicinity, AD-462942, prepared for Office of Civil Defense by Guy B. Panero, Inc., New York, NY, April 1965.

Guy B. Panero, Inc., Underground Installations -- Foreign, prepared for U.S. Army Chief of Engineers, by Guy B. Panero, Inc., New York, NY, October 1948a.

Guy B. Panero, Inc., Underground Installations (Summary), Contract W-49-129-Eng-59, prepared for U.S. Army Chief of Engineers by Guy B. Panero, Inc., New York, NY, October 1948b.

Haaland, C.M., "Underground Shelter -- How Much Fallout Protection?" Journal of Civil Defense 16 (3), pp. 10-13 (June 1983).

Haaland, C.M., "How Effective Can Shelters Be?" Journal of Civil Defense 15 (6), pp. 23-26 (December 1982).

Haaland, C.M., "Offense-Defense Cost Studies," pp. 29-34 in Annual Progress Report -- Civil Defense Research Project, March 1969 - March 1970, ORNL-4566 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, April 1971.

Haaland, C.M, Systems Analysis of U.S. Civil Defense via National Blast Shelter Systems, ORNL-TM-2457, prepared for U.S. Atomic Energy Commission by Oak Ridge National Laboratory, Oak Ridge, TN, March 1970.

Haaland, C.M., "A Complete System for Hardened Civil Defense," pp. 18-27 in Annual Progress Report -- Civil Defense Research Project, March 1968 - March 1969, ORNL-4413 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, October 1969.

Haaland, C.M., and C.V. Chester, "Will Technology Make Shelters Obsolete?" ORBIS 25 (3), pp. 771-794 (Fall 1981).

Haaland, C.M., C.V. Chester, and E.P. Wigner, Survival of the Relocated Population of the U.S. After a Nuclear Attack (Final Report), ORNL-5041 (AD-A026362), Oak Ridge National Laboratory, Oak Ridge, TN, June 1976.

Haaland, C. M., and M. T. Heath, Passive-Active Defense Studies for the Detroit Metropolitan Area (Final Report), ORNL-4818 (AD-759416), Oak Ridge National Laboratory, Oak Ridge, TN, December 1972.

Haaland, C. M., E. P. Wigner and J. V. Wilson, Active and Passive Defense Interaction Studies: Vol. 1. Summary, Models, and Calculations, ORNL-TM-3485 (AD-747006), Oak Ridge National Laboratory, Oak Ridge, TN, December 1971.

Hadala, P.F., Effect of Constitutive Properties of Earth Media on Outrunning Ground Shock from Large Explosions, Technical Report

S-73-6 (AD-768176), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, August 1973.

Haerter, A., "Problems of Civil Defence -- Shelter Ventilation," AEGIS International (Switzerland) 3 (4), pp. 44-50 (August/September 1984).

Hahl, R.G., Manually Powered Pumping Equipment, AD-403824, U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, VA, October 1962.

Hale, J.F., and H.F. Behls, Psychological, Engineering, and Physiological Evaluation of Shelter Equipment and Procedures (Volume II -- Laboratory Studies), GARD Report 1292, prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, February 1967.

Haltiwanger, J.D., C.C. Tung, G.C. Feng, and W.C. Schnorbrich, Attachments and Connections to Buried Structures, AD-475427, prepared for U.S. Naval Civil Engineering Laboratory by University of Chicago, Urbana, IL, October 1965.

Hamberg, W.A., A.M. Salee, and R.H. Watkins, Study of Tactical Movement Concepts and Procedures for Civil Defense Planning, ORI-TR-210 (AD-421933), prepared for Office of Civil Defense by Operations Research, Inc., Silver Springs, MD, August 1963.

Hammes, J.A., Shelter Occupancy Studies at the University of Georgia, 1965, with Appendices, AD-635501 and AD-635502, prepared for Office of Civil Defense by University of Georgia, Athens, GA, December 1965.

Hammes, J.A., Shelter Occupancy Studies at the University of Georgia 1964, AD-615004, prepared for Office of Civil Defense by University of Georgia, Athens, GA, December 1964.

Hammes, J.A., Shelter Occupancy Studies at the University of Georgia 1962-1963, with Appendices, AD-439251, prepared for Office of Civil Defense by University of Georgia, Athens, GA, December 1963a.

Hammes, J.A., Shelter Occupancy Studies at the University of Georgia 1962-1963 (A Summary of the Final Report), AD-439396, prepared for Office of Civil Defense by University of Georgia, Athens, GA, December 1963b.

Hammes, J.A., and T.R. Ahearn, Shelter Occupancy Studies at the University of Georgia, prepared for Office of Civil Defense by University of Georgia, Athens, GA, December 1967.

Hammes, J.A., and T.R. Ahearn, Shelter Occupancy Studies at the Univesity of Georgia, 1966, prepared for Office of Civil Defense by University of Georgia, Athens, GA, December 1966.

Hammes, J.A., R.R. Ahearn, J.W. Foughner, M.E. Braun, M.P. Beussee, and S.T. Wright, Shelter Occupancy Studies at the University of Georgia with Appendices, Reports No. 4950 and 4951, prepared for Office of Civil Defense by University of Georgia, Athens, GA, December 1968.

Hanifan, D.T., W.V. Blockley, M.B. Mitchell, and P.H. Strudwick, Physiological and Psychological Effects of Overloading Fallout Shelters, AD-420449, prepared for Office of Civil Defense by Dunlap and Associates, Inc., Santa Monica, CA, April 1963.

Harrenstein, H., et al, Yielding Membrane Elements in Protective Construction (Final Report), AD-625782, prepared for Office of Civil Defense by University of Arizona, Engineering Research Laboratory, Tucson, AZ, May 1965.

Harvey, E.C., Alternative Approaches to Financing a Nation-Wide Shelter Program: A Contributing Investigation to the Area-Wide Shelter System Study, SRI Project MU-4536 (AD-635930), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, January 1964 (updated April 1966).

Harvey, T.F., Influence of Civil Defense on Strategic Countervalue Fatalities, UCID-19370 (DE-82-015396), Lawrence Livermore Laboratory, Livermore, CA, April 1982.

Harvey, T.F., and F.J.D. Serduke, Fallout Model for System Studies, UCRL-52858, Lawrence Livermore Laboratory, Livermore, CA, October 1979.

Havers, J. A., Structural Materials for Hardened Personnel Shelter (Final Report), IITRI Project M-254 (AD-429134), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, December 1963.

Havers, J.A., and J.J. Lukes, Structural Cost Studies for Hardened Shelters (500-Man and 10-Man Capabilities) (Final Draft Report), IITRI Project M6064 (AD-458314), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, August 1964.

Havers, J. A., C. B. Monk, Jr., and E. H. Koeller, An Investigation of Minimal Equipment Needs in Personnel Shelters (Final Report), IITRI Project No. M6064/4 (AD-631424), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, June 1965.

Heck, W., Underground Construction: A Multipurpose American Alternative, 1015-78 (AD-B030476), Air Command and Staff College, Maxwell Air Force Base, AL, April 1978.

Hedge, J. C., and T. E. Waterman, Fire Test Ratings for Shelter Components (Final Technical Report - Period: 15 October 1967 to 15 May 1969), IITRI Project J6132 (AD-700940), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, May 1969.

Heierli, W., and L. Jundt, "Public Transport Works as Civil Defence Shelters," AEGIS International (Switzerland) 2 (2), pp. 8-17 (April/May 1983).

Heierli, W., and L. Jundt, "Weapon Effects on Shelters," AEGIS International (Switzerland) 1 (4), pp. 12-18 (August/September 1982)

Heierli, W., L. Jundt, and E. Kessler, The Civil Defense Facility in the Sonnenberg Tunnel in Lucerne (Switzerland), Federal Office of Civil Defense, Berne, Switzerland, November 1985.

Heinzmann, H., The Civil Defense System of Switzerland, Federal Office of Civil Defense, Berne, Switzerland, 1985.

Hellberg, E.N., Performance of the AMF 36- and 48-Inch Blast Closure Devices, NCEL-TN-529 (AD-417900), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, August 1963.

Hellberg, E.N., Performance of the Swedish Rapid-Closing Anti-Blast Valve, NCEL-TN-439 (AD-275196), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, May 1962.

Hendrey, R.N., R.O. Lyday, G.L. Bilbro, M.S. Ranade, K.J. Reeves, and V.L. Herold, Development of Guidelines for Enhancement of the Grid-Oriented Public Shelter Model (Final Report), RTI/-2083/00-05F (AD-A107545), prepared for Federal Emergency Management Agency by Research Triangle Institute, Research Triangle Park, NC, September 1981.

Henninger, R.H., C. Krishnakumar, and R. Tsal, Adequacy of Wind Ventilation in Upgraded Shelters, GARD Final Report A1-11/1713 (AD-A087676), prepared for Federal Emergency Management Agency by GARD Inc., Niles, IL, June 1980.

Henninger, R.H., and C. A. Madson, Natural Ventilation Test of an Above-ground Fallout Shelter in Chicago, Illinois, GARD Report 1268-81 (AD-641701), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, August 1966.

Herzog, W.T., W.L. Wells, and W.J. Cromartie, Shelter Medical Support System Study (Part I and Part II - Final Report), R-OU-107(AD-415614), prepared for Office of Civil Defense by Research Triangle Institute, Durham, NC, August 1963.

Heugel, W.F., and D.I. Feinstein, Shelter Evaluation Program (Final Report), IITRI Project No. M6088 (AD-818658), prepared for Office of Civil Defense by IIT Research Institute Chicago, IL, February 1967.

Hibbard, R.R., D.S. Hyman, F.H. Murphy, L.M. Pietrzak, S.R. Rubens, and W.R. Thomsen, Hard Rock Tunneling System Evaluation and Computer Simulation, GRC-CR-1-190 (AD-733667), General Research Corporation, Arlington, VA, September 1971.

Hickman, R.G., Aerodynamic Considerations in Open Shelters, UCRL-53583, prepared for Federal Emergency Management Agency by Lawrence Livermore National Laboratory, Livermore, CA, November 1984.

Hickman, R.G., and C.A. Meier (eds.), Proceedings of the Asilomar Conference on Fire and Blast Effects of Nuclear Weapons (17th), May 30-June 3, 1983, CONF-8305107 (AD-A132780), Lawrence Livermore Laboratory, Livermore, CA, July 1983.

Hill, E.L., et al., Structural Characteristics of NFSS Buildings (A Five Volume Final Report), R-OU-237, prepared for Office of Civil Defense by Research Triangle Institute, Research Triangle Park, NC, June 1967.

Hill, E.L., J.G. Caldwell, and W.K. Grogan, Determination of Configuration for Ventilation (Final Report), RTI-OU-177 (AD-468676), prepared for Office of Civil Defense by Research Triangle Institute, Durham, NC, July 1965.

Hill, E.L., and C.M. Parker, Cost and Protection Analysis of NFSS Structures (Final Report), R-OU-154 (AD-464268), prepared for Office of Civil Defense by Research Triangle Institute, Durham, NC, January 1965.

Hobbs, N.P., and K.R. Wetmore, PIVUL -- A Computer Code for Rapid Assessment of the Vulnerability of Simple Structures to Blast, ARBRL-CR-00417 (AD-A085715), prepared for U.S. Army Ballistic Research Laboratory by Kaman-AviDyne, Burlington, MA, March 1980.

Hognestad, E., "Yield Line Theory for the Ultimate Flexural Strength of Reinforced Concrete Slabs," Journal of the American Concrete Institute 24 (7), Proceedings Vol. 49, pp. 637-656 (March 1953).

Hollon, S.D., P.C. Kendall, S. Norsted, and D. Watson, "Psychological Responses to Earth-Sheltered, Multilevel, and Aboveground Structures With and Without Windows," Underground Space 5, pp. 171-178 (1980).

Holmes and Narver, Inc., Engineering Study for Tunnel Grid Blast Shelter Concept for a Portion of City of Detroit, Michigan, ORNL-HN-2, prepared for Oak Ridge National Laboratory, by Holmes and Narver, Inc., Los Angeles, CA, June 1965a.

Holmes and Narver, Inc., Structural and Shielding Considerations in the Design of Hardened Facilities, HN-183 (AD-479254), prepared for Defense Atomic Support Agency by Holmes and Narver, Inc., Los Angeles, CA, June 1965b.

Holmes and Narver, Inc., Design Manual, AEC Test Structures, Volume I: Design of Blast Resistant Structures, TID-16347-3, prepared for U.S. Atomic Energy Commission by Holmes and Narver, Inc., Los Angeles, CA, December 1961.

Holmes and Narver, Inc., AEC Group Shelter, CEX-58.7, prepared for U.S. Atomic Energy Commission by Holmes and Narver, Inc., Los Angeles, CA, January 1960.

Home Office and the Central Office of Information (United Kingdom), Domestic Nuclear Shelters -- Technical Guidance (A Home Office Guide), Second Edition, Southampton, England, 1982.

Hoot, B.B., Portable Bunker Tests and Evaluation, Technical Report N-71-6 (AD-885285), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, June 1971.

Hoot, B.B., G.L. Carre, J.E. McDonald, J.L. Decell, J.V. Dawsey, and P.J. Rieck, Evaluation of Field Fortifications, Technical Report N-74-5 (AD-921985), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, August 1974.

Hoot, B.B., et al., Army Aircraft Protective Structures Designs (Report 9 - Design, Construction, and Evaluation of Small Shelters), Technical Report N-69-8 (AD-901054), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, June 1972.

Hopwood, D., "Generate Your Own Electricity," Protect and Survive Monthly (United Kingdom) 2 (1), pp. 7-10 (January 1982).

Hori, T., Feasibility of Low Cost Ventilation Techniques (Final Report), SRI Project 4949-251 (AD-670950), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, December 1967.

Hubbell, J.H., and L.V. Spencer, Shielding Against Gamma Rays, Neutrons, and Electrons from Nuclear Weapons -- A Review and Bibliography (a National Bureau of Standards Monograph), NBS-Mono-69, U.S. Department of Commerce, National Bureau of Standards, Washington, DC, February 1964.

Huddleston, C.M., D.R. Doty, and W.C. Ingold, Nuclear Radiation Shielding in the Design of Hardened Structures, NCEL-TR-599, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, October 1968.

Huff, W.L., Expedient Upgrading of Existing Structures for Fallout Protection (Final Report), Technical Report N-78-1 (AD-A053763), prepared for Defense Civil Preparedness Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, April 1978.

Huff, W.L., Collapse Strength of a Two-Way Reinforced Concrete Slab Contained Within a Steel Frame Structure (Final Report), Technical Report N-75-2 (AD-A012825), prepared for Defense Civil Preparedness Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, June 1975.

Hughes-Caley, F., Cooling Water for Fallout Shelters (Final Report), AD-641199, prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, March 1966.

Hughes-Caley, F., and R. Kiang, Blast-Closure Valves (Final Report), SRI Project 4949-211 (AD-636321), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, August 1965.

Hummell, J.D., Design and Cost Study of Heat Exchangers for Air-Cycle Shelter Cooling Systems (Summary Report), AD-620167, prepared for Stanford Research Institute by Battelle Memorial Institute, Columbus, OH, March 1965.

Hummell, J.D., and W.D. Beck, The Study of a Shelter Cooling System Using Methanol as the Heat Sink and as the Fuel (Final Report), AD-637953, prepared for Office of Civil Defense by Battelle Memorial Institute Columbus, OH, June 1966.

Humphreys, C.M., A. Henschel, and D.H.K. Lee, Sensible and Latent Heat Losses from Occupants of Survival Shelters, AD-648467, prepared for Office of Civil Defense through the Department of Health, Education, and Welfare by Occupational Health Research and Training Facility, Cincinnati, OH, December 1966.

Hyde, D.W., and S.A. Kiger, DIRECT COURSE Blast Door and Entryway Design and Evaluation (Final Report), Technical Report SL-84-13

(AD-A146814), prepared for Federal Emergency Management Agency by U.S. Army Engineer Waterways Experiment Station Vicksburg, MS, July 1984.

IIT Research Institute, Suburban Community Fallout Shelter Study (Summary of Interim Report), IITRI Report No. P-6009 (AD-442891), prepared for Office of Defense by IIT Research Institute, Chicago, IL, July 1964.

IIT Research Institute, Shelter Equipment Planning Guidelines (Final Report), AD-602124, prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, June 1964.

Ingram, L.F., Attenuation of Airblast in Protective Structures, Miscellaneous Paper No. 1-608 (AD-450996) U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, November 1963.

International Council of Educational Facility Planners, Protected Educational Facilities in Found Space, TR-78, U.S. Department of Health, Education and Welfare and Defense Civil Preparedness Agency, Washington, DC, May 1973.

Irving, D., The Destruction of Dresden, published by Holt, Rinehart and Winston, New York, NY, 1964.

Isenberg, J., A Review of Current Analytic and Field Testing Programs Status of Research in Structure-Medium Interaction, DNA-3976F, prepared for Defense Nuclear Agency by Wiedlinger Associates, Menlo Park, CA, December 1975.

Isenberg, J., G.L. Wojcik, and H. Hikooyeh, Dynamic Analysis of Buried Structures Including Catastrophic Failure, DNA-6229F, prepared for Defense Nuclear Agency by Weidlinger Associates, Menlo Park, CA, December 1975.

Isenberg, M.W., and R. Allen, Natural Ventilation for Fallout Shelters (Final Report - Phase I and Phase II), AD-680217, prepared for Office of Civil Defense by the Pennsylvania State University, Department Architectural Engineering and Institute for Building Research, University Park, PA, April 1968.

Isenberg, M.W., E.R. McLaughlin, C.H. Wheeler, G.H. Albright, E.R. Queer, R.B. Allen, and K. Pukita, Natural Ventilation for Fallout Shelter (Interim Report), AD-489656, prepared for Office of Civil Defense Pennsylvania State University, Department of Architectural Engineering and the Institute for Building Research, University Park, PA, January 1966.

Iverson, J.H., Existing Structures Evaluation Part II: Window Glass and Applications (Final Report), SRI Project No. MU-6300-020 (AD-687294), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, December 1968.

Iwanski, E.C., and A. Wiedermann, Feasibility Study of Personnel Closures, AD-232051, prepared for U.S. Army Corps of Engineers by Armour Research Foundation, Chicago, IL, August 1959.

Jackson, J.G., Jr., Site Characterization for Probabilistic Ground Shock Predictions (Final Report), Miscellaneous Paper No. SL-828 (AD-A120398), prepared for Defense Nuclear Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, July 1982.

Jago, A.G., and A.L. Kapil, Lighting Kit, GARD Final Report 1508 (AD-716360) prepared for the Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, September 1970.

Jensen, G.F., Existing Structures Evaluation Part I: Structural Steel Connections (Final Report), SRI Project No. MU-6300-024 (AD-701088), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, December 1969.

Jensen, G.F., Shelter Water Supply Study: Cost Implications of Emergency Sources (Final Report), AD-659800, prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, August 1967.

Jester, G.E., An Experimental Investigation of Soil-Structure Interaction in Cohesive Soil, Technical Report N-70-7, Vol. I and II, (AD-706210 and AD-706211), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, March 1970.

Johnston, B., A Door Design for Tunnel Closure, AFSWC-TR-59-58, U.S Air Force Special Weapons Center, Kirtland AFB, NM, October 1959.

Jones, T.K., Effect of Evacuation and Sheltering on Potential Fatalities from a Nuclear Exchange, published by Boeing Aerospace Company, Seattle, WA, August 1977.

Jones, W.A., W. Johnson, and B.K. Reid, Air Blast Evaluation Studies on CEMO Mark II Family Blast Shelter, DRES-TN-299 (AD-904818), Defense Research Establishment, Suffield Ralston, Alberta, Canada, July 1972.

Jordan, D., Weapon Effects Program for the IBM PC and PC/XT (Electronic Handbook Series), DNA-EH-84-01-G and HTI-SDR-84-2, prepared for the Defense Nuclear Agency by Horizons Technology, Inc., San Diego, CA, December 1984.

Jordan, D., and L.M. Welsh, Blast Effects Program for the IBM PC and PC/XT (Electronic Handbook Series), DNA-EH-84-02-G, and HTI-SDR-84-227, prepared for the Defense Nuclear Agency by Horizon Technology, Inc., San Diego, CA, December 1984.

Kamath, R.V., and M.D. Wright, Supplemental Study: Surge-Period Shelter Programs (Final Report), RTI/1798/00-08F (AD-A097282), prepared for Federal Emergency Management Agency by Research Triangle Institute, Research Triangle Park, NC, March 1981.

Kamath, R.V., and M.D. Wright, Feasibility and Cost Analysis of Surge Period Shelter Programs (Final Report), RTI/1798/00-05F, (AD-A086244), prepared for Federal Emergency Management Agency by Research Triangle Institute, Research Triangle Park, NC, June 1980.

Kapil, A.L., Blast Vulnerability of Shelter Supplies, GARD Final Report 1518 (AD-744789), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, March 1972.

Kapil, A.L., Non-Corrodible Dual-Purpose Water Container, GARD Final Report 1479 (AD-720219), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, February 1970.

Kapil, A.L., Storage Sanitary Container, GARD Final Report 1448 (AD-842690), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, April 1968.

Kapil, A.L., and C.E. Rathmann, Shelter Ventilator Studies, GARD Final Report 1477-1 (AD-726737), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, January 1971.

Kapil, A.L., H.M. Sitko, and J.M. Buday, Ventilation Kits, GARD Final Report 1477 (AD-704350), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, November 1969.

Karagozian, J., and W.T. Tsai, Analysis of Shallow Buried Structures, DNA-6219F, prepared for the Defense Nuclear Agency by Karagozian and Case, Los Angeles, CA, October 1979.

Karbashov, U., Special Processing and Antiblast Equipment, FSTC-HT-1289-84 (AD-B089681), translated from Russian for the U.S.Army Foreign Science and Technology Center, Charlottesville, VA, November 1984.

Kearny, C.H., Nuclear War Survival Skills, ORNL-5037, Oak Ridge National Laboratory, Oak Ridge, TN, September 1979 (Available from NWS Research, P.O. Box 1144, Coos Bay, OR 97420 and from Citizens Preparedness Group of Greater Kansas City, Inc., P.O. Box 23209, Kansas City, MO 64141).

Kearny, C.H., Expedient Shelter Construction and Occupancy Experiments, ORNL-5039, Oak Ridge National Laboratory, Oak Ridge, TN, March 1976.

Kearny, C.H., How to Make and Use a Homemade, Large-Volume, Efficient Shelter-Ventilating Pump: The Kearny Air Pump, ORNL-TM-3916, Oak Ridge National Laboratory, Oak Ridge, TN, August 1972.

Kearny, C.H., "Physiology of Heat Stress," pp. 44-62 in Annual Progress Report -- Civil Defense Research Project, March 1965 - March 1966, ORNL-TM-1531 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, November 1966.

Kearny, C.H., Shelter Furnishings for Efficient Living Space, ORNL-TM-1428, Oak Ridge National Laboratory, Oak Ridge, TN, March 1966.

Kearny, C.H., Components of Shelter Systems, Hudson Institute, Harmon-on-Hudson, NY, August 1963.

Kearny, C.H., and C.V. Chester, Blast Tests of Expedient Shelters in the DICE THROW Event, ORNL-5347 (AD-A052913), Oak Ridge National Laboratory, Oak Ridge, TN, March 1978.

Kearny, C.H., and C.V. Chester, Blast Tests of Expedient Shelters (Middle North Series, MIXED COMPANY Event) ORNL-4905, Oak Ridge National Laboratory, Oak Ridge, TN, January 1974.

Kearny, C.H., C.V. Chester, and E.N. York, Blast Tests of Expedient Shelters in the MISERS BLUFF Event (Final Report), ORNL-5541 (AD-A083966), Oak National Laboratory, Oak Ridge, TN, January 1980.

Kelleher, G.J., A Damage-Limiting Shelter-Allocation Strategy, IDA-HQ-65-3518 and S-186 (AD-615779), prepared for Office of Civil Defense by Institute for Defense Analyses, Arlington, VA, April 1965.

Keller, J.A., A Study of World War II German Fire Fatalities, DC-TN-1050-3, prepared for Office of Civil Defense by Dikewood Corporation, Albuquerque, NM, April 1966.

Kennedy, T.E., Dynamic Tests of a Model Flexible-Arch-Type Protective Shelter, Miscellaneous Paper N-71-3 (AD-723960), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, April 1971.

Kennedy, T.E., Dynamic Response of a Model Buried Field Shelter Operation PRAIRIE FLAT, Technical Report N-70-6 (AD-704957), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, March 1970.

Kennedy, T.E., J.W. Ball, B.B. Hoot, and P.J. Rieck, Expedient Field Fortifications for Use Against Nuclear Weapons (Final Report), Technical Report N-74-7 (AD-923220), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, September 1974.

Kennedy, T.E., and J.T. Ballard, Dynamic Test of a Model Flexible-Arch-Type Protective Shelter (Report I - Pilot Test), Technical Report No. 1-768 (AD-651349), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, April 1967.

Kessler, J., and L. Levoy, A Study of Blast Closure Devices, AFSWC-TDR-62-10 (AD-274646), prepared for the Air Force Special Weapons Center, by American Machine and Foundry Co., Greenwich, CT, February 1962.

Kiang, R., Blast-Actuated Closure Valves for Personnel-Type Shelters (Final Report - Phase II), SRI Project 4949-211 (AD-661648), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, February 1967.

Kiger, S.A., P.S. Eagles, and J.T. Baylot, Response of Earth-Covered Slabs in Clay and Sand Backfills (Final Report), Technical Report SL-84-18 (AD-A149296), prepared for Defense Nuclear Agency and U.S. Department of the Army by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, October 1984.

Kiger, S.A., and J.V. Getchell, Vulnerability of Shallow-Buried Flat-Roof Structures; Foam HEST 7, Technical Report SL-80-7 (Report 5), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, February 1982.

Kiger, S.A., and J.V. Getchell, Vulnerability of Shallow-Buried Flat-Roof Structures; Foam HEST 1 and 2, Technical Report SL-80-7 (Report 1), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, September 1980.

Kiger, S.A., and T.R. Slawson, Design Validation Experiments for the Key Worker Blast Shelter, AD-P001809, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1977.

Kiger, S.A., T.R. Slawson, and D.W. Hyde, Vulnerability of Shallow-Buried Flat-Roof Structures (Report 6, Final Report: A Computational Procedure), Technical Report SL-80-7, prepared for Defense Nuclear Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, September 1984.

Knott, A.W., G.H. Albright, M.W. Isenberg, and R.E. Kummer, The Planning and Development of Expedient Shelter Facilities, AD-465123, prepared for U.S. Naval Civil Engineering Laboratory by Pennsylvania State University, University Park, PA, March 1965.

Kopala, F.A., Acute Intestinal Disorders in Shelter Groups (Final Report), SRI Project No. MU-4949-610 (AD-825057), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, December 1967.

Korell, M.L., "Financing Earth-Sheltered Housing: Issues and Opportunities," Underground Space 3 (6), pp. 297-301 (1979).

Korolev, V.I., (ed.), What Everyone Must Know and be Able to Do (When Under Attack by Weapons of Mass Destruction) -- Instructions for the Population, FSTC-HT-268-84 (AD-B085423), translated from Russian for U.S. Army Foreign Science and Technology Center, Charlottesville, VA, June 1984.

Kreiliger, P., "The Equipping of Shelters," AEGIS International (Switzerland), pp. 28-34, December 1982/January 1983.

Kriebel, A.R., Nuclear Weapons Blast Phenomena - Volume II: Blast Wave Interaction - Supplement 1: Airblast in Tunnels and Chambers, URS-7050-2 (AD-906986), URS Research Company, San Mateo, CA, October 1972.

Krishnakumar, C.K., J.B. Koh, S.F. Fields, and R.H. Henniger, Evaluation of Shelter Ventilation by Model Tests -- Option 1, Below Ground Shelters, GARD-A1-51-1 (AD-A137230), prepared for Federal Emergency Management Agency by GARD, Inc., a Division of GATX, Niles, IL, September 1983.

Krishnakumar, C.K., C.K. Schafer, S.F. Fields, and R.H. Henninger, Evaluation of Shelter Ventilation by Model Tests -- Option 2, GARD Report A1-51-2 (AD-A146845), prepared for the Federal Emergency Management Agency by GARD Division of Chamberlain National, Niles,IL, September 1984.

Krupka, R.A., An Evaluation of the Shelter Potential in Mines, Caves and Tunnels, HI-507-RR, prepared for the U.S. Department of the Army, Office of Civil Defense, by the Hudson Institute, Inc., Harmon-on-Hudson, NY, June 1965.

Krupka, R.A., On Shelter Costs, HI-391-RR/3 (AD-602846), prepared for Office of Civil Defense by Hudson Institute, Harmon-on-Hudson, NY, June 1964a.

Krupka, R.A., Overcrowding Potential, HI-361-RR/4 (AD-602847), prepared for Office of Civil Defense by Hudson Institute, Harmon-on-Hudson, NY, June 1964b.

Krupka, R.A., Collateral Damage, HI-361-RR/5 (AD-602849), prepared for Office of Civil Defense by Hudson Institute, Harmon-on-Hudson, NY, June 1964c.

Krupka, R.A., et al., Shelter Configuration Factors (Engineering and Cost Analysis), AD-405709, prepared for Office of Civil Defense by Guy B. Panero, Inc., New York, NY, April 1963.

Kucher, V., and J. Harrison, Air Shock Filling of a Model Room, BRL-R-2011 (AD-A670937), U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1977.

Lacayo, H., Jr., and M.A. Sullivan, Significance of Fallout Ingress into Shelters, USNRDL-TR-68-3 (AD-830340), U.S. Naval Radiological Defense Laboratory, San Francisco, CA, October 1967.

Lamb, H.C., Aboveground Concrete Masonry Family Fallout Shelter, PSDC-TR-11 (AD-817129), prepared for Office of Civil Defense by Protective Structures Development Center, Fort Belvoir, VA, February 1967.

Lamb, H.C., and M.M. Dembo, Ultimate Strength of Chopped Wire Reinforced Small Scale Mortar Slabs (Final Report), PSDC-TR-19 (AD-652884), prepared for Office of Civil Defense by Protective Structures Development Center, Fort Belvoir, VA, January 1967.

Lamb, H.C., et al., Dual Purpose Community Fallout Shelters--200 and 1000 Persons, PSDC-TR-1 (AD-612624), Protective Structures Development Center, Fort Belvoir, VA, October 1964.

Lamoureur, R.L., Warning Considerations for the Detroit Tunnel-Grid Blast Shelter Concept, ORNL-TM-1719, prepared for Office of Civil Defense by Oak Ridge National Laboratory, Oak Ridge, TN, March 1967.

Lane, C.A., "Waterproofing Methods and Products," Earth Shelter Living, No. 32, pp. 23-27 (March/April 1984).

Lang, C., Vulnerability Characteristics of Emergency Operating Centers (EOCs) in Blast-Risk Areas (Final Report), R-7611-4314 (AD-A035868), prepared for Defense Civil Preparedness Agency by Agbabian Associates, El Segundo, CA, January 1977.

Lang, C., Blast-Resistant Characteristics of State and Local Emergency Operating Centers (EOC's) (Final Report), R-7427-1-3865 (AD-A016663), prepared for the Defense Civil Preparedness Agency by Agbabian Associates, October 1975.

Latter, A.I., and E.A. Martinelli, Active and Passive Defense, P-3165-1 (AD-676973), prepared for the U.S. Department of Defense by Rand Corporation, Santa Monica, CA, August 1968.

Lauck, F.W., and V.D. Overbye, Novel Power Sources for Survival Shelters, AD-431610, prepared for Office of Civil Defense by

A.O. Smith Corporation, Long Range Research Laboratory, Milwaukee, WI, March 1963.

Lauck, F.W., V.D. Overbye, and D.D. Hart, Small Auxiliary Power Systems for Shelters, AD-603227, prepared for Office of Civil Defense by A.O. Smith Corporation, Long Range Research Laboratory, Milwaukee, WI, May 1964.

Lawrence Radiation Laboratory, A Study of Design and Cost Data for Family and Small-Group Fallout Shelters, UCRL-6654, University of California, Livermore, CA, October 1961.

LeDoux, J.C., Protection Factor Estimator, OCD-TM-64-1, Office of Civil Defense, Washington, DC, May 1964.

LeDoux, J.C., Analysis of the Critical Shielding Volume for Underground Shelters, NCEL-TN-381 (AD-250640), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, February 1960.

LeDoux, J.C., Nuclear Radiation Shielding Provided by Buried Shelters, NCEL-TR-025, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, October 1959.

LeDoux, J.C., and A.B. Chilton, Attenuation of Gamma Radiation Through Two-Legged Rectangular Ducts and Shelter Entranceways--An Analytical Approach, NCEL-TN-383, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, January 1961.

LeDoux, J.C.,and L.K. Donovan, Shielding Factors for Various Geometric Shapes, NCEL-TR-080 (AD-254344), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, April 1961.

LeDoux, J.C., and P.J. Rush, Response of Earth Confined Flexible Arch Structures in High-Overpressure Regions, WT-1626, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, January 1961.

Lee, W., H.C. Leong, C. Jee, and M.G. Hershberger, Design of Tests for the Effects of Mass Fires on Shelter Occupants (Final Report), NRDL-TRC-67 and HNS-80 (AD-658734), prepared for Office of Civil Defense through the U.S. Naval Radiological Defense Laboratory by Hazleton-Nuclear Science Corporation, Palo Alto, CA, September 1966

Leland, E.P., Emergency Personnel Shelters, AERDL-1554-TR (AD-304269), U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, VA, November 1958.

Leskys, A.G., and G.E. Albritton, Behavior of Circular Tubes Buried in Sand Under Dynamic Loading, Miscellaneous Paper No. 1-964 (AD-666768), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, February 1968.

Levy, J.C., A Manual for the Management of Foods in Licensed Fallout Shelters, AD-403829 prepared for the Department of Defense by Cornell University, School of Hotel Administration, Ithaca, NY, April 1963a.

Levy, J.C., Food Service Procedures in Fallout Shelters, AD-403714, prepared for the Department of Defense by Cornell University, School of Hotel Administration, Ithaca, NY, April 1963b.

Libovicz, B.A., Shelter Portable Ventilation Equipment, GARD Final Report 1430 (AD-682713), prepared for Office of Civil Defense by General American Transportation, Research Division, Niles, IL, January 1969.

Libovicz, B.A., and H.F. Behls, Shelter Package Ventilation Kit, GARD-1244 (AD-629633), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, October 1965.

Libovicz, B.A., and H.F. Behls, Experimental Prototype Package Ventilation Kit, First Structural and Human Factors Test, GARD 1278-4.1 (AD-633233), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, May 1965.

Libovicz, B.A., C.A. Madson, H.F. Behls, and G. Engholm, Summer Ventilation Test of 200-Occupant Basement Shelter in Milwaukee, Wisconsin, GATC-IR-MRD-1195-54-2 (AD-450915), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, April 1964.

Libovicz, B.A., R.B. Neveril, and H.F. Behls, Preproduction Prototype Package Ventilation Kit, Second Structural and Human Factors Test, GARD-1278-4.2, (AD-632963), prepared for Office of Civil Defense, by General American Transportation Corporation, Research Division, Niles, IL, August 1965.

Libovicz, B.A., J.W. Van Schoyck, and G. Engholm, Ventilation Test of an Identified Basement Shelter in Houston, Texas, GATC--IR-MRD-1195-52, prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, January 1963.

Lin, N., J. O'Donnell, D. Yauger, R. Burt, and D. Kling, The Diffusion of the Slanting Techniques: A Study of the Direct Mail Shelter Development System (DMSDS), AD-753215, prepared for the Defense Civil Preparedness Agency by State University of New York, Albany, NY, June 1972.

Lin, N., J. O'Donnell, D. Yauger, and C. Melik, Evaluation of Alternative Means of the Diffusion of the Slanting Techniques

(Final Report), AD-773396, prepared for Defense Civil Preparedness Agency byState University of New York, Albany, NY, November 1973.

Lipner, N., D.C. Anderson, and P.K. Dai, Ground Motion Environments for Generic Site Conditions, DNA-3872F, prepared for Defense Nuclear Agency by TRW Systems Group, Redondo Beach, CA, December 1975.

Lis, S.J., and H.F. Behls, Ventilation Equipment Analysis for Basement Shelters, GARD Final Report 1278, (AD-670027), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, February 1968.

Logan, D.L., Evaluation of Projectile Impact on Earth-Covered Structures, ESL-TR-84-22, (AD-A145087), Air Force Engineering and Services Laboratory, Tyndall AFB, FL, June 1984.

Logothetti, T.J., R.L. Goen, J.W. Ryan, C.A. Kamradt, C.K. Wiehle, F.C.A. Allen, and E.P. Webster, Parametric Study of Shelter System Costs (Final Report), SRI Project MU-6250-010 (AD-688958), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, January 1969.

Long, D., Nuclear War Survival, published by Long Survival Publications (P.O. Box 163), Wamego, KS, January 1982.

Long, E.F., Analytical Studies, Investigation, and Preliminary Designs of Door and Foundation Seals for Protective Structures, AFSWC-TR-59-49 (AD-460852), prepared for the Air Force Special Weapons Center by Sandberg-Serrell Corporation, Pasadena, CA, May 1959.

Longinow, A., Probability of People Survival in a Nuclear Weapon Blast Environment (Final Report), IITRI-J6479-FR (AD-A087600), prepared for Federal Emergency Management Agency by IIT Research Institute, Chicago, IL, May 1980.

Longinow, A., Survivability in a Nuclear Weapon Environment (Final Report), IITRI Project No. J6427 (AD-A076026), prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, May 1979.

Longinow, A., Survivability on the Fringe of High Risk Areas (Final Report), IITRI Project J6389, (AD-A062752), prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, August 1978.

Longinow, A., Survivability in Crisis Upgraded Shelters (Final Report), IITRI Project J6390 (AD-A055764), prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, February 1978.

Longinow, A., Survivability in a Direct Effects Environment (Analysis of 50 NFSS Buildings), IITRI Project J6311, prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, July 1974.

Longinow, A., Civil Defense Shelter Options for Fallout and Blast Protection (Dual-Purpose) (Final Report), IITRI Project M6101 (AD-655284), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, May 1967.

Longinow, A., S.A. Guralnick, and J. Mohammadi, Failure Criteria for Blast Loads Structures -- A Review, AD-P001800, Illinois Institute of Technology, Chicago Department of Civil Engineering, Chicago, IL, June 1982.

Longinow, A., E. Hahn, A. Wiedermann, and S. Citki, Casualties Produced by Impact and Related Topics of People Survivability in a Direct Effects Environment (Final Report), IITRI Project J6303 (AD-A011108), prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, August 1974.

Longinow, A., and R.P. Joyce, Load Tests of a Wood Floor Over a Basement (Final Report), IITRI Project J6451 (AD-A092688), prepared for Federal Emergency Management Agency by IIT Research Institute, Chicago, IL, June 1980.

Longinow, A., J. Kalinowski, C.A. Kot, and F. Salzberg, Civil Defense Shelter Options: Deliberate Shelters - Volume I (Final Report), IIT Project J6144 (AD-740174), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, December 1971a.

Longinow, A., J. Kalinowski, C.A. Kot, F. Salzberg, Civil Defense Shelter Options: Deliberate Shelters - Volume II (Final Report), IITRI Project J6144 (AD-740175), prepared for Office of Civil Defense by ITT Research Institute, Chicago, IL, December 1971b.

Longinow, A., J. Kalinowski, C.A. Kot, and F. Salzberg, Civil Defense Shelter Options (Interim Report), IITRI Project J6144, prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, November 1970.

Longinow, A., G. Ojdrovich, L. Bertram, and A. Wiedermann, People Survivability in a Direct Effects Environment and Related Topics (Final Report), IITRI Project J6144 (AD-764114), prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, May 1973.

Longinow, A., and O.J. Stepanek, Civil Defense Shelter Options for Fallout and Blast Protection (Single-Purpose) (Final

Report), IITRI Project J6115 (AD-674633), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, June 1968.

Longinow, A., T.E. Waterman, and H.S. Napadensky, *Combined Effects of Blast and Fire on Personnel Survivability*, AD-P0493, IIT Research Institute, Chicago, IL, August 1982.

Longinow, A., T.E. Waterman, and A.N. Takata, *Assessment of Combined Effects of Blast and Fire on Personnel Survivability*, IITRII-J6483 (AD-A117958), IIT Research Institute, Chicago, IL, June 1982.

Longinow, A., and A. Wiedermann, *Relative Structural Considerations for Protection from Injury and Fatality at Various Overpressures* (Final Report), IITRI Project J6365 (AD-049040), prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, June 1977.

Longinow, A., A. Wiedermann, S. Citko, and N. Iwankiw, *Debris Motion and Injury Relationships in all Hazard Environments* (Final Report), IITRI Project J6334 (AD-A030815), prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, July 1976.

Longinow, A., M-Y. Wu, and J. Mohammadi, *Damage Functions for Upgraded Shelters*, IITRI-J6528 (AD-A119701), IIT Research Institute, Chicago, IL, August 1982.

Longmire, R.M., and L.D. Mills, *Navy Structures* (Operation UPSHOT- KNOTHOLE, Projects 3.11 to 3.16), WT-729, U.S. Department of the Navy, Bureau of Yards and Docks, Washington, DC, May 1955.

Ludwig, F.L., *Urban Climatological Studies* (Interim Report No. 1), SRI Project MU-4949-580 (AD-657248), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, February 1967.

Ludwig, F.L., and J.H.S. Kealoha, *Urban Climatological Studies* (Final Report), SRI Project MU-6300-140 (AD-672071), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, March 1968.

Luscher, U., "Buckling of Soil-Surrounded Tubes," *Journal of the Soil Mechanics and Foundation Division (Proceedings of the American Society of Civil Engineers) 92* (SM6), pp. 211-228 (November 1968).

Luscher, U., *Behavior of Flexible Underground Cylinders*, AFWL-TR-65-99, prepared for U.S. Air Force Weapons Laboratory by Massachusetts Institute of Technology, Department of Civil Engineering, Cambridge, MA, September 1965.

Lutz, F.W., P.D. Lynch, and S.B. Lutz, Abo Revisited -- An Evaluation of the Abo Elementary School and Fallout Shelter, AD-744340, prepared for the Defense Civil Preparedness Agency by the Pennsylvania School Study Council, Inc., University Park, PA, June 1972.

Lynch, F.X., "Adequate Shelters and Quick Reactions to Warning: A Key to Civil Defense," Science 142, pp. 665-667 (1963).

MacDonald, C.L., Shelter Package Ventilation Kit Development (Final Report), AD-458655, prepared for Office of Civil Defense by Ralph M. Parsons Company, New York, NY, March 15, 1965.

McDonnell, C., and J. Velletri, Radiation Distribution Within a Multi-story Structure (Final Report), NRDL-TRC-68-7 (AD-671888), prepared for the Office of Civil Defense by CONESCO, a Division of Flow Corporation, Watertown, MA, February 1967.

McDonnell, C., and J. Velletri, An Experimental Evaluation of Roof Reduction Factors, PSCD-TRT-16 (AD-645661), prepared for the Protective Structures Development Center by CONESCO, a Division of Flow Corporation, Cambridge, MA, May 1966.

McGavin, C.T., Shelter Potential in Parking Garages (Final Report) APT-1170 (AD-715416), prepared for Office of Civil Defense by Applied Parking Techniques, Inc., Reston, VA, November 1970.

McGrath, R.K., Dynamic Response of Concrete Arch Bunkers (Event DIAL PACK; Project LN314A), Technical Report N-71-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, July 1971.

McMullan, F.A., J.C. Wright, H.S. Anderson, and S. Trustman, Budget Allocation for Shelter Systems (Final Report), RTI Project OU-230-1 (AD-656940), prepared for Office of Civil Defense by Research Triangle Institute, Research Triangle Park, NC, June 1967.

McNulty, J.W., An Experimental Study of Arching in Sand, Technical Report No. 1-674, (AD-A615511), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, May 1965.

McVay, M.K., Test and Analysis of Upgraded One-Way Reinforced Concrete Floor Slabs (Final Report), Technical Report SL-81-4 (AD-A103544), prepared for Federal Emergency Management Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, July 1981.

Madson, C.A., R.J. Baschiere, H.F. Behls, and G. Engholm, Summer Ventilation Test of an Above-Ground Shelter in Bozeman, Montana, GATC-IR-MRD-1195-56-1 (AD-453069), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, November 1964.

Madson, C.A., H.F. Behls, and G. Engholm, Natural Ventilation Test of an Above-Ground Fallout Shelter in Bozeman, Montana, GATC Interim Report MRD-1195-56-2 (AD-453070), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, November 1964.

Madson, C. A., B. A. Libovicz, H. F. Behls, and G. Engholm, Ventilation Test of a 210-Man Aboveground Fallout Shelter in Wilmington, North Carolina, GATC-IR-MRD-1195-55-1 (AD-450948), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, February 1964.

The Manhattan Engineer District, The Atomic Bombings of Hiroshima and Nagasaki, U.S. Department of the Army, Washington, DC, 1946.

Marston, A., The Theory of External Loads on Closed Conduits, Bulletin No. 96, Iowa Engineering Experiment Station, Ames, IA, 1930.

Martin, T.L., Jr., and D.C. Latham, Strategy for Survival, published by University of Arizona Press, Tucson, AZ, 1963.

Mason, H.G., Effects of Structural Compressibility on Active and Passive Arching in Soil-Structure Interaction, URS-645-8 and DASA-1718 (AD-625732), prepared for Defense Atomic Support Agency by URS Corporation, Burlingame, CA, November 1965.

Mason, H. G. and D. Walter, An Exploratory Study to Assess the Magnitude of OCD Foundation Problems (Final Report), URS-693-3 (AD-688186), prepared for Stanford Research Institute and Office of Civil Defense, by URS Systems Corporation, Burlingame, CA, November 1968.

Mason, W.R., and J.E. Schroeder, Design, Development, and Evaluation of a 25-ft by 48-ft Disaster Shelter, NCEL-TM-081 (AD-021260), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, April 1953.

Mather, R.L. Ground Roughness Effects in Fallout Radiation Fields -- Problems of Analysis of Measurements, USNRDL-TR-68-62 (AD-67322), U.S. Naval Radiological Defense Laboratory, San Francisco, CA, March 1968.

Meier, H. A., and G. Engholm, Psychological, Engineering, and Physiological Evaluation of Shelter Equipment and Procedures (Volume I - Summary and Review), GARD Report 1292 (AD-653018), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, February 1967.

Meier, H.A., R.W. Smith, and M.W. Gaynor, Specialized Evaluations of Shelter Equipment and Procedures (Final Report), GARD--FR-1292 (AD- 669258), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, January 1968.

Melichar, J.F., Analysis of the Effect of Shelter Openings on Blast Protection (Final Report), URS-773-6 (AD-724710), prepared for Office of Civil Defense by URS Research Company, San Mateo, CA, September 1970.

Melichar, J.F., The Air-Blast-Induced Environment Within Civil Defense Blast-Slanted Shelters (Final Report), URS-755-3 (AD--708564), prepared for Office of Civil Defense, by URS Research Company, Burlingame, CA, November 1969.

Melichar, J.F., Air-Blast-Induced Aerodynamic Effects in Blast-Slanted Basement Shelters (Final Report), URS-692-3 (AD-691773), prepared for Office of Civil Defense by URS Research Company, Burlingame, CA, January 1969.

Melichar, J.F., The Propagation of Blast Waves into Chambers, BRL-MR-1920 (AD-672476), U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, March 1968.

Merritt, J.L., and N.M. Newmark, Nuclear Geoplosics: A Sourcebook of Underground Phenomena and Effects of Nuclear Explosions -- Vol. V. Effects on Underground Structures and Equipment, DASA-1285 (V), (AD-443589), prepared for Defense Atomic Support Agency by Stanford Research Institute, Menlo Park, CA, May 1964.

Merritt, J.L., and N.M. Newmark, Design of Underground Structures to Resist Nuclear Blast (Final Report), NP-7854, prepared for Office of Civil Defense by University of Illinois, Urbana, IL, April 1958.

Metz, D., "The Aesthetics of the Underground Building," in Collected Papers Presented at Earth Sheltered Housing Conference and Exhibition - I, Minneapolis, MN, April 9-11, 1980.

Miller, C.F., Firefighting Operations in Hamburg, Germany, During World War II: Excerpts from the Hamburg Fire Department Documents on the Air Attacks During World War II, Appendixes 3, 4, and 5 and Photographs, AD-753346, prepared for the Defense Civil Preparednes Agency by United Research Services, Inc., Burlingame, CA, April 1972.

Miller, C.F., *The Radiological Assessment and Recovery of Contaminated Areas*, CEX-57.1, U.S. Naval Radiological Defense Laboratory, San Francisco, CA, March 1958.

Miller, C.F., and J.W. Kerr, *Field Notes on World War II German Fire Experience*, SRI Project No. MU-5070, prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, October 1965.

Mitchell, D.L., *An Optimization Study of Blast Shelter Deployment, -- Volumes I, II, and I*, LAMBDA Report 3 (AD-659377 through AD-659379), prepared for the Office of Civil Defense by the Institute for Defense Analysis, Arlington, VA, September 1966.

Mitchell, J.H., *Nuclear Explosion Effects on Structures and Protective Construction -- A Selected Bibliography*, TID-3092, U.S. Atomic Energy Commission, Washington, DC, April 1961.

Mixter, G.J., *Thermal Radiation Casualties at Nagasaki: A Retrospective Analysis*, Project Report No. 16, prepared for Defense Atomic Support Agency by U.S. Naval Applied Science Laboratory, Brooklyn, NY, February 1967.

Molodykh, V.I., et al., *Civil Defense of the USSR -- Antiradiation Shelters in Rural Areas (Instructions for the Population)*, ORNL-TR-2745, translated from Russian by Oak Ridge National Laboratory, Oak Ridge, TN, October 1973.

Moreland, F.L., et al., *Earth-Covered Buildings: An Exploratory Analysis for Hazard and Energy Performance*, MA1-81 (PB 82-189564), prepared for Federal Emergency Management Agency by Moreland Associates, Fort Worth, TX, November 1981.

Morrison, T., *Design Procedures for Shock Isolation Systems of Underground Protective Structues -- Volume I: Structure Interior Motions Due to Air Blast Induced Ground Shock*, RTD-TDR-63-3096 (Vol. I), (AD-444624), prepared for U.S. Air Force Weapons Laboratory by General American Transportation Corporation, Niles, IL, June 1964.

Murakoa, J.S., *Shelter Habitability Studies -- The Effects of Oxygen Depletion and Fire Gases on Occupants of Shelter*, NCEL-TR-144, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, July 1961.

Murakoa, J.S., *Shelter Habitability Studies: Odors and Requirements for Ventilation*, NCEL-TR-146, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, May 1961.

Murdock, A.E., Hasty Type Air Raid Shelters (Operation TUMBLER), WT-560, Armed Forces Special Weapons Project, Albuquerque, NM, February 1953.

Murphy, H.L., Upgrading Basements for Combined Nuclear Weapons Effects: Predesigned Expedient Options II (Final Report), SRI Project 6876 (AD-A097915), prepared for Federal Emergency Management Agency by SRI International, Menlo Park, CA, July 1980a.

Murphy, H.L., Upgrading Basements for Combined Nuclear Weapons Effects: Predesigned Expedient Options II -- Supplement with Applied Examples, SRI Project 6876 (AD-A097916)), prepared for Federal Emergency Management Agency by SRI International, Menlo Park, CA, July 1980b.

Murphy, H.L., Upgrading Basements for Combined Nuclear Weapons Effects: Predesigned Expedient Options, SRI Project 5622, (AD-A054409), prepared for Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA, October 1977.

Murphy, H.L., Feasibility Study of Slanting for Combined Nuclear Weapons Effects (Revised) (Volume 1-Interim Report), SRI Project MU-6300-501 (AD-724711), prepared for Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA, October 1970a.

Murphy, H.L., Feasibility Study of Slanting for Combined Nuclear Weapons Effects (Revised) -- Volume 2: Appendices (Interim Report), SRI Project MU-6300-501 (AD-724712), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, October 1970b.

Murphy, H.L., Feasibility Study of Slanting for Combined Nuclear Weapons Effects (Summary), SRI-MU-6300-500 (AD-692312), prepared for the Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, June 1969.

Murphy, H.L., Ground Motion Predictions for Nuclear Attack Area Studies, SRI Project MU-6300-470 (AD-690208), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, May 1967.

Murphy, H.L., and J.E. Beck, Maximizing Protection in New EOCs from Nuclear Blast and Related Effects: Guidance Provided by Lecture and Consultation, SRI-P-4620 (AD-A039499), prepared for Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA, September 1976.

Murphy, H.L., J.R. Rempel, and J.E. Beck, Slanting in New Assessments for Combined Nuclear Weapons Effects: A Consolidated

Printing of Four Technical Reports (Volumes 1, 2, and 3), AD-A023237, prepared for Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA, October 1975.

Murphy, H.L., C.K. Wiehle, and E.E. Pickering, Upgrading Basements for Combined Nuclear Weapons Effects: Expedient Options, SRI Project 4270 (AD-A030762), prepared for Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA, May 1976.

Murphy, J.R., H.K. Shah, and T.K. Tzeng, Analysis of Low Frequency Ground Motions Induced by Near-Surface and Atmospheric Explosions, DNA-TR-81- 157, prepared for Defense Nuclear Agency by S-Cubed, La Jolla, CA, August 1982.

Nakano, Y., Numerical Computation of the Shock Wave Diffracted by a Circular Cylindrical Cavity in Elastic-Plastic Media, Research Report 279 (AD-702906), U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH, January 1970.

Narver, D.L., Jr., and D.T. Robbins, Engineering and Cost Considerations for Tunnel Grid Blast Shelter Concept, ORNL-TM-1183, prepared for Oak Ridge National Laboratory by Holmes and Narver, Inc., Los Angeles, CA, August 1965.

Nash, P.T., W.E. Baker, E.D. Esparza, P.S. Westine, N.W. Blaylock, Jr., R.E. White, and M.G. Whitney, "Do-It-Yourself" Fallout Blast Shelter Evaluation, UCRL-15605 and SWRI-7531 (AD-A141259), prepared for the Federal Emergency Management Agency through Lawrence Livermore National Laboratory by Southwest Research Institute, San Antonio, TX, March 1984.

National Academy of Sciences, Proceedings of the Symposium on Protective Structures for Civilian Populations (April 19-23 1965), Washington, DC, 1965.

National Academy of Sciences, Proceedings of Environmental Engineering in Protective Shelters (a meeting held February 8-10, 1960, in Washington, DC), published by National Academy of Sciences and National Research Council, Washington, DC, 1960.

National Civil Defense Guidance Group Office (China), Civil Air Defense Project Design Standards, China Report, Science and Technology, No. 123 (translated from Chinese by the Foreign Broadcast Information Service), available as JPRS-78862 from U.S. Joint Publications Research Service, Arlington, VA, August 1981.

National Research Council, The Effects on the Atmosphere of a Major Nuclear Exchange, published by the National Academy Press, Washington, DC, 1985.

National Technical Information Service, Civil Defense, 1976 - November 1984 (Citations from the Energy Database), PB-85-851053, Springfield, VA, November 1984.

Nehlsen, W.R., Development of a Biological Oxidation Package Waste Disposal Unit, NCEL-TR-225 (AD-081276), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, July 1955.

Nehnevajsa, J., Home Basement Sharing: An Analysis and a Possible Approach to Planning, AD-A030970, prepared for Defense Civil Preparedness Agency by University of Pittsburg, University Center for Urban Research, Pittsburg, PA, September 1976.

Neveril, R.B., and H.F. Behls, Shelter Lighting Kit, GARD Report 1400 (AD-655904), prepared for Office of Civil Defense by Transportation Corporation, Research Division, Niles, IL, January 1967.

Neveril, R.B., and H.F. Behls, Friction Loss in Flexible Plastic Air Duct, GARD Report 1278-2 (AD-632964), prepared for Office of Civil Defense by American Transportation Corporation, Research Division, Niles, IL, October 1965.

Neveril, R.B., and A.L. Kapil, Water Container Liner, GARD Final Report 1427 (AD-667965), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, 1L, September 1967.

Nevrincean, G., and E.F. Witt, Blast Valve Tests (Middle North Series, DIAL PACK and PRAIRIE FLAT Events) DNA-POR-6742 and WT-6742 (AD-753804), Defense Nuclear Agency, Washington, DC, December 1972.

Newlin, H. E., and G. L. Hayes, Further Studies on the Development of a Nutritionally Adequate Fallout Shelter Ration (Final Report -- Part I of II), MRI Project No. 2769-B, (AD-632351), prepared for Office of Civil Defense by Midwest Research Institute, Kansas City, MO, March 1966a.

Newlin, H.E., and G.L. Hayes, Further Studies on the Development of a Nutritionally Adequate Fallout Shelter Ration (Final Report -- Part II), MRI Project No. 2769-B, (AD-632350), prepared for Office of Civil Defense by Midwest Research Institute, Kansas City, MO, March 1966b.

Newman, J.S., Attenuation of Shock Waves in Tunnel Shelters, ORNL-TM-1622, Oak Ridge National Laboratory, Oak Ridge, TN, September 1966.

Newmark, N.M., Design of Openings for Buried Shelters, Contract Report No. 2-67 (AD-427616), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, July 1963.

Newmark, N.M., "An Engineering Approach to Blast Resistant Design," Transactions of the American Society of Civil Engineers 121, p. 45-61 (1956).

Newmark, N.M., and J.D. Haltiwanger, Air Force Design Manual--Principles and Practices for Design of Hardened Structures, AFSWC-TDR-62-138 (AD-295408), prepared for Air Force Special Weapons Center by University of Illinois, Department of Civil Engineering, Urbana, IL, December 1962.

Newmark, N.M., and G.K. Sinnamon, Air Blast Effects on Underground Structures (Operation UPSHOT-KNOTHOLE, Project 3.8), WT-727, University of Illinois, Urbana, IL, January 1954.

Nielsen, J.P., "Canadian Fiberglass Blast Shelter Trials," Protect and Survive Monthly (United Kingdom) 1 (4), pp. 11-15 (April 1981).

Nieman, T.F., Better Read Than Dead -- The Complete Book of Nuclear Survival, published by Paladin Press (P.O. Box 1307), Boulder, Co, 1981.

Norbutas, J.A., Piston Plate Blast Valve Development, Technical Note N-1237, (AD-905722) Naval Civil Engineering Laboratory, Port Hueneme, CA, October 1972.

Norbutas, J., R. Chapler, and D. Pal, High Explosive Field Test of Buships Blast Valve, NCEL-TN-1180, Naval Civil Engineering Laboratory, Port Hueneme, CA, October 1971.

Nordell, W.J., Active Systems for Blast-Resistant Structures, NCEL-TR-611, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, February 1969.

Norman Steuer Associates, Corrugated Board Furniture Study, AD-408355, prepared for Office of Civil Defense by Norman Steuer Associates, San Francisco, CA, June 1963.

Nuclear Regulatory Commission, Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, WASH-1400 and NUREG-75/014, Washington, DC, October 1975.

O'Brian, T., "A Survey of Civil Defence Measures in the Western Industrial Nations," AEGIS International (Switzerland) 3 (3), pp. 4-10 (June/July 1984).

Office of Civil and Defense Mobilization, Fallout Shelter Surveys: Guide for Architects and Engineers (Appendix 2 - Annex 10, National Shelter Plan), NP-10-2 National Plan Appendix Series, Washington, DC, May 1960 (reprinted July 1960).

Office of Civil Defense, Twelve Protected Schools -- School Houses Designed with Fallout Protection, TR-65, Washington, DC, February 1971.

Office of Civil Defense, Shelters in New Homes, TR-60, Washington, DC, December 1969.

Office of Civil Defense, Fallout Shelter Design Techniques -- Apartment Buildings, TR-54, Washington, DC, January 1969.

Office of Civil Defense, Fallout Protection in Military Construction, TR-50, Washington, DC, May 1968.

Office of Civil Defense, Design Modification Studies, TR-51, Washington, DC, April 1968.

Office of Civil Defense, Fallout Shelter in Industrial and Commerce Buildings, TR-48, Washington, DC, December 1967.

Office of Civil Defense, Community Development and Civil Defense, TR-46, Washington, DC, June 1967.

Office of Civil Defense, Buildings with Fallout Shelter, TR-37, Washington, DC, July 1966.

Office of Civil Defense, Schools Built with Fallout Shelter, TR-33 Washington, DC, February 1966.

Office of Civil Defense, New Buildings with Fallout Protection, TR-27, Washington, DC, January 1965.

Office of Civil Defense, Industrial Architecture -- Fallout Shelters, TR-21, Washington, DC, November 1963.

Office of Civil Defense, Dual Purpose Suburban Community Shelter for 100, 500, and 1000 Persons and a Blast Capacity of 5, 25, and 50 Psi (Protective Structures Division Shelter Design Series), OCD-PSD-DSC-45-2, Washington, DC, June 1963.

Office of Civil Defense, Parking Garage and Community Shelter for 5,000 Persons with a Blast Resistance Capacity of 5, 25 and 50 Psi (Protective Structures Division Shelter Design Series), OCD-PSD-DSG-35-2, Washington, DC, April 1963.

Office of Civil Defense, Dual Purpose Blast Resistant School and Community Shelter for 350, 550, and 1100 Persons and a Blast Capacity of 5, 25, and 50 Psi (Protective Structures Division Shelter Design Series), OCD-PSD-DSS-55-3, Washington, DC, March 1963.

Office of Civil Defense, Minimum Technical Requirements for Shelter Doors and Hatches (Blast), OCD-TM-62-5, Washington, DC, January 1963a.

Office of Civil Defense, Minimum Technical Requirements for Manual and Manual-Electrical Ventilators, OCD-TM-62-6, Washington, DC, January 1963b.

Office of Civil Defense, Minimum Technical Requirements for Anti-Blast Valves, OCD-TM-62-7, Washington, DC, January 1963c.

Office of Civil Defense, Incorporation of Shelter into Schools (Interim Edition), PSD-PG-80-1 (AD-708552), Washington, DC, November 1962a.

Office of Civil Defense, Incorporation of Shelter into Apartments and Office Buildings, PSD-PG-80-4 (AD-708557), Washington, DC, November 1962b.

Office of Civil Defense, Dual Purpose Parking Garage and Community Shelter for 5,000 Persons (Protective Structures Division Shelter Design Series), OCD-PSD-DSG-35-1, Washington, DC, revised September 1962a.

Office of Civil Defense, Dual Purpose School and Community Shelter for 350, 550, and 1100 Persons (Protective Structures Division Shelter Design Series), OCD-PSD-DSS-5-1, Washington, DC, revised September 1962b.

Office of Civil Defense, A Dual Purpose Suburban Community Center and Shelter for 100, 500, and 1000 Persons (Protective Structures Division Shelter Design Series), OCD-PSD-DSC-45-1, Washington, DC, August 1962a (reprinted April, 1963).

Office of Civil Defense, A Below Ground School and Community Shelter for 2400 People in Artesia, New Mexico, OCD-ECS-55-4, Washington, DC, August 1962b.

Office of Civil Defense, Minimum Technical Requirements for Family Shelters, OCD-TM-61-1, Washington, DC, August 1962c.

Office of Civil Defense, Minimum Technical Requirements for Group (Community) Shelters, OCD-TM-61-3, Washington, DC, August 1962d.

Office of Civil Defense, Shelter in Federal Buildings, Washington, DC, (no date).

Office of Civil Defense in Cooperation with U.S. Department of Agriculture Federal Extension Service, Rural Fallout Shelter Analysis Workshop Student Manual, SM-18-1, Washington, DC, January 1964.

Oklahoma State Department of Education, A Case for Underground Schools, Prepared for Defense Civil Preparedness Agency in cooperation with Oklahoma Civil Defense, Oklahoma City, OK, 1978.

Ormerod, R., Nuclear Shelters, A Guide to Design, published by the Architectural Press, Ltd., London, England, 1983.

Ort, F.G., and M.D. Mears, Development of the Closure, Protective Shelter, Anti-Blast, 600 cfm, E19R1, Technical Report CWRL-2269, Chemical Warfare Labs, U.S. Army Chemical Center, Edgewood, MD, January 1959.

Oster, R.E., Sr., Refugee -- USA; No. 1, published by Survival Ink (914 Pinehurst Dr.), Arlington, TX, 1984a.

Oster, R.E., Sr., Refugee -- USA; No. 2 -- Food, published by Survival Ink (914 Pinehurst Dr.), Arlington, TX, 1984b.

Oster, R.E., Sr., Refugee -- USA; No. 3 -- Wild Plant Food, published by Survival Ink (914 Pinehurst Dr.), Arlington, TX, 1985a.

Oster, R.E., Sr., Refugee -- USA; No. 4 -- Nuclear Shelters, published by Survival Ink (914 Pinehurst Dr.), Arlington, TX, 1985b.

Ostroukh, F.I., Construction of Quickly Erectable Blast and Radiation Shelters, JPRS-63455, Translation of a U.S.S.R. Monographby the U.S. Joint Publications Research Service, Arlington, VA, November 1974.

Ostrowski, W.L., Description of the American Chemical Society's CBR Fallout Shelter, published by American Chemical Society, Washington, DC, March 1962.

O'Sullivan, J.J., Proceedings of the Second Protective Construction Symposium -- Deep Underground Construction, March 24, 25, 26, 1959 (Volume I), R-341 (AD-231659), Rand Corporation, Santa Monica, CA, 1959a.

O'Sullivan, J.J., Proceedings of the Second Protective Construction Symposium -- Deep Underground Construction, March 24, 25, 26, 1959 (Volume II), R-341 (AD-231660), Rand Corporation, Santa Monica, CA, 1959b.

Owen, W.L., Radiological Protective Construction -- Principles for the Protection of Facilities and their Inhabitants Against Fallout, USNRDL-467 (AD-275990), U.S. Naval Radiological Defense Laboratory, San Francisco, CA, January 1962.

Palacious, N., and T.E. Kennedy, The Dynamic Response of Buried Concrete Arches (Project 3.2, Operation SNOWBALL), TR-1-797 (AD-661632), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, September 1967.

Park, R., and W.L. Gamble, Reinforced Concrete Slabs, published by John Wiley and Sons, New York, NY, 1980.

Perla, H.F., and H.F. Haller, Engineering Study of Underground Highway and Parking Garage and Blast Shelter for Manhattan Island, ORNL-TM-1381, prepared for the Oak Ridge National Laboratory by Holmes and Narver, Inc., Los Angeles, CA, December 1965.

Perret, W.R., Ground Motion Studies at High Incident Overpressure (Operation PLUMBBOB -- Project 1.5), WT-1405, Sandia Corporation Albuquerque, NM, June 1960.

Peterson, R.E., R.D. Bernard, R.S. Tansley, A.B. Willoughby, and C. Wilton, Damage Function Rating Procedure for Flat Slab Basement Shelters, SSI-8143-9, (AD-A123187), prepared for the Federal Emergency Management Agency by Scientific Service, Inc., Redwood City, CA, December 1982.

Petras, J.L., A.H. Hoffer, R.F. Worley, and K.C. Brown, Donn Blast Test No. 1 (MISERS BLUFF Event II-II, Final Report), Donn Incorporated, Westlake, OH, March 1979a.

Petras, J.L., A.H. Hoffer, R.F. Worley, and K.C. Brown, Donn Blast Shelter Test No. 2 (MISERS BLUFF Event II-II, Final Report), Donn Incorporated, Westlake, OH, March 1979b.

Petty, J.B., I, and W.L. Brooks, Cost Estimates for Providing Biological Agent Protection to Fallout Shelters, DEIS No. 1 (AD-450037), prepared for Office of Civil Defense by Director of Engineering and Industrial Services, Edgewood Arsenal, MD, October 1964.

Pickering, E.E., and J.L. Bockholt, Probabilistic Air Blast Failure Criteria for Urban Structures (Final Report), SRI Project 6300 (AD-738558), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, November 1971.

Pinkston, J.M., Jr., Attenuation of Airblast in Open Entranceways of Blast-Protective Structures, (U.S. Project 6, Canadian HE Test Program), Miscellaneous Paper No. 1-631 (AD-450997), U.S.

Army Engineer Waterways Experiment Station, Vicksburg, MS, February 1964.

Porteous, L.G., Design Modifications and 1962 Cost Analysis for a Standardized Series of Fallout Shelters, USNRDL-TR-582, prepared for the Office of Civil Defense by the U.S. Naval Radiological Defense Laboratory, San Francisco, CA, September 1962.

Poruk, J.U., B. A. Libovicz, and G. Engholm, Ventilation Test of a 330-Man Aboveground Shelter in Chicago, Illinois, GATC Interim Report MRD-1195-53 (AD-450913), prepared for Office of Civil Defense by General American Transportation Corporation, MRD Division, Niles, IL, June 1963.

Protective Structures Development Center, Expedient Group Fallout Shelters Trailer Vans, PSDC-TR-5, prepared for the Office of Civil Defense, Protective Structures Development Center, Fort Belvoir, VA, July 1964.

Public Health Service, Fallout Protection for Hospitals, Publication No. 791 (Revised), U.S. Department of Health, Education, and Welfare, Washington, DC, February 1962.

Purdie, A.C., SES 100 Ton TNT Blast Trial - Suffield, Alberta, August 1961: The Effect of Blast on Reinforced Concrete Slabs with and without Earth Cover, AWRE Report No. E1/64, United Kingdom Atomic Energy Authority, Weapons Research Development, Aldermaston, Berkshire, January 1964.

Quarantelli, E., Sheltering and Housing after Major Community Disasters: Case Studies and General Observations, AD-A113904, Ohio State University Research Foundation, Columbus, OH, January 1982.

Ralph M. Parsons, Co., Protective Construction Concepts, AD-850286, prepared for the Directorate of Civil Engineering, Headquarters, U.S. Air Force, Washington, DC, November 1968.

Ramskill, E.A., et al., Studies of the Bureau of Yards and Docks Protective Shelter; I. Winter Trials, NRL Report 5882 (AD-405886), U.S. Naval Research Laboratory, Washington, DC, December 1962.

Randall, P.A., Damage to Conventional and Special Types of Residences Exposed to Nuclear Effects (Operation TEAPOT, Project 31.1), WT-1194 (AD-611160), Office of Civil and Defense Mobilization; Federal Housing Administration; and Housing Home Finance Agency, Washington, DC, April 1961.

Raska, E., and R. Grayson (eds.), Proceedings of the DIRECT COURSE Symposium (9-13 April 1984) (a twelve volume report), DNA-POR-

7119-1 through -12 and WT-7119-1 through -12, Defense Nuclear Agency, Kirtland AFB, NM, January 1985.

Rathmann, C.E., Bunking System Concepts, GARD Final Report 1509 (AD-722243), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, December 1970.

Rathmann, C. E., Air Distribution in Shelters Due to Kearny Pumps and Pedal Ventilators, GARD Final Report 1476-1 (AD-175405), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, August 1970.

Rathmann, C. E., Configuration Effects on Ventilation in Belowgrade Shelters, GARD Final Report 1476 (AD-704964), prepared for Office of Civil Defense by General American Transportation Corporation, Research Division, Niles, IL, August 1969.

Read, P.A., Models of Ground Roughness in a Fallout Field, USNRDL-TR-84 (AD-658878), U.S. Naval Radiological Defense Laboratory, San Francisco, CA, June 1967.

Regional and Urban Planning Implementation, Inc., Federal Incentives for Solar Homes: An Assessment of Program Options--Methodological Appendices (Final Report-Backup), HUD/RES/203 (PB-274654), prepared for U.S. Department of Housing and Urban Development in cooperation with U.S. Energy Research and Development Administration by Regional and Urban Planning Implementation, Inc., Cambridge, MA, November 1977.

Reid, G.H., Misty Castle Series - MILL RACE Event, DNA-POR-7072 (AD-B062998), Defense Nuclear Agency, Kirtland Air Force Base, NM, December 1981.

Reid, G.H., and R.M. Grayson, Proceedings of the MILL RACE Preliminary Results Symposium, 16-18 March 1982 (Volume II), DNA-POR-7073-2 (AD-B070003), Defense Nuclear Agency, Kirtland Air Force Base, NM, July 1982a.

Reid, G.H., and R.M. Grayson, Proceedings of the MILL RACE Preliminary Results Symposium, 16-18 March 1982 (Volume I), DNA-POR-7073-3, (AD-B070004), Defense Nuclear Agency, Kirtland Air Force Base, NM, July 1982b.

Rempel, J.R., Debris Distribution as a Parameter in Blast/Fire Interaction, SRI-HSU-8561 (AD-A104669), prepared for Federal Emergency Management Agency by Stanford Research Institute, Menlo Park, CA, June 1980.

Rempel, J. R., Ground Shock and the Survival of the Contents of Personnel Shelters (Part I -- Resistance of Human and Inanimate

Contents of Hardened Shelters to Nuclear-Induced Ground Motion), SRI Project MU-4949-431 (AD-832639), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, April 1967.

Reynolds, R. S., R. E. Faw, and M. J. Robinson, A University Design Study of Reduction Factors in Typical American Houses with Fallout Shelters (Final Report), KEES-SR-92 (AD-722856), prepared for Office of Civil Defense by Kansas State University, Radiation Shielding Facility, Manhattan, KS, February 1971.

Richmond, D.R., E.G. Damon, I.G. Bowen, E.R. Fletcher, and C.S. White, Air-Blast Studies with Eight Species of Mammals, DASA-1854, prepared for Defense Atomic Support Agency by Lovelace Foundation for Medical Education and Research, Albuquerque, NM, August 1966.

Richmond, D.R., E.R. Fletcher, and R.K. Jones, The Effects of Air-Blast on Sheep in Two-Man Foxholes, DASA-2711 and POR-LN-401 (AD-730874), prepared for Defense Atomic Support Agency by Lovelace Foundation for Medical Education and Research, Albuquerque, NM, June 1971.

Robbins, D.T., and D.L. Narver, Jr., Engineering Study for Tunnel Grid Blast Shelter Concept for a Portion of City of Detroit, Michigan, ORNL-TM-1223, prepared for Oak Ridge National Laboratory by Holmes and Narver, Inc., Los Angeles, CA, October 1965.

Roberts, J.E., C.S. White, and T.L. Chiffelle, Effects of Overpressures in Group Shelters on Animals and Dummies (Operation UPSHOT-KNOTHOLE, Project 23.15, Part I), WT-798, Lovelace Foundation, Albuquerque, NM, September 1953.

Robinson, M.J., R.S. Reynolds, C.A. Burre, and R.E. Faw, A University Design Study of Protection Factors in Typical American Houses (Final Report), KEES-SR-84 (AD-701079), prepared for Office of Civil Defense by Kansas State University, Radiation Shielding Facility, Manhattan, KS, November 1969.

Rockett, F.C., A Low-Casualty Program of Hardened and Dispersed Shelters, HI-685-P, Hudson Institute, Inc., Harmon-on-Hudson, NY, April 1966.

Rockett, F.C., and W.M. Brown, On the Design of Risk-Oriented, Low-Cost Fallout Shelter Systems, HI-486/3-RR, prepared for Office of Civil Defense by Hudson Institute, Harmon-on-Hudson, NY, March 1967.

Rockett, F.C., and W.M. Brown, An Analysis of Local Protection Factor Requirements and Resources, HI-486-RR, prepared for the Office of Civil by Hudson Institute, Inc., Harmon-on-Hudson, NY, Defense, August 1965.

Roembke, J.E., Retest and Evaluation of Antiblast Valves (Operation HARDTACK, Phase II, Preliminary Report, Project 70.3), ITR-1717, Office of Civil and Defense Mobilization Test Group, Washington, DC, October 1958a.

Roembke, J.E., Effect of Nuclear Weapons on OCDM Family Fallout Shelter (Operation HARDTACK, Phase II, Preliminary Report, Project 70.4), ITR-1718, Office of Civil and Defense Mobilization, Washington, DC, October 1958b.

Romualoi, J.P., and M.R. Ramey, Effects of Impulsive Loads on Fiber-Reinforced Concrete Beams (Final Report), AD-630843, prepared for Office of Civil Defense by Carnegie Institute of Technology, Pittsburgh, PA, October 1965.

Rooke, A.D., Jr., Ejecta Distribution from Near-Surface Explosions on a Layered Soil: DISTANT RUNNER Events 2 and 3, Miscellaneous Paper SL-83-9 (AD-B076226), prepared for Defense Nuclear Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, June 1983.

Ross, S., R. Trumbull, and G.Z. Williams, U.S. Navy Fallout and Blast Shelter -- National Naval Medical Center Survival Trial Study, Technical Report No. 4 (AD-662223), Naval Medical Research Institute, Bethesda, MD, July 1965.

Rotz, J.V., Detailed Damage Analysis of NFSS Structures with Detailed Descriptions of Damage and Degraded PF (Final Report), URS-658-7 (AD-672060), prepared for Office of Civil Defense by URS Corporation, Burlingame, CA, September 1967.

Royal United Services Institute for Defence Studies (London), Nuclear Attack: Civil Defence -- Aspects of Civil Defence in the Nuclear Age, published by Pergamon Press, Inc., Elmsford, NY, 1982.

Rush, P.J., Developments in Protective Shelter Systems, NCEL-TR-35, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, April 1965.

Russel, J.W., and E.N. York, "Expedient Industrial Protection From Nuclear Attack," Journal of Practical Civil Defence (United Kingdom), No. 8, pp. 13-32 (May/June 1984).

Ryan, J.W., and S. Baum, Analysis of Slanted Blast Shelter Programs, SRI-EGU-1368 (AD-771964), prepared for the Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA, December 1972.

Sager, E.V., C.W. Hulburt, and R.J. Sullivan, High Risk Areas of the United States Identified by Congressional District, AD-A069521, System Planning Corporation, Arlington, VA, May 1979.

Sager, R.A., Concrete Arch Studies (Project 3.2, OPERATION SNOWBALL), Miscellaneous Paper No. 1-736 (AD-471342), prepared for Defense Atomic Support Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, August 1965.

Salzberg, F., Design of Test for Simulating Urban Area Burns (Final Report), USNRDL-TRC-56 (AD-645466), prepared for Office of Civil Defense through U.S. Naval Radiological Defense Laboratory by IIT Research Institute, Chicago, IL, June 1966.

Sampsell, D.F., Thermal Transient Response of Underground Shelters, NCEL-TN-711 (AD-621377), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, September 1965.

Sandoval, C.A., A Handbook for Estimating Material Requirements and Costs of Shelter Doors Subjected to Long-Duration Blast Loading, RM-2277 (AD-225891), Rand Corporation, Santa Monica, CA, October 1958.

Santini, D.J., et al., A Preliminary Evaluation of Crisis Relocation Fallout Shelter Options -- Volume I: A Summary, ANL/EES-TM-227 (Vol I), prepared for Federal Emergency Management Agency by Argonne National Laboratory, Argonne, IL, March 1982a.

Santini, D.J., et al., A Preliminary Evaluation of Crisis Relocation Fallout Shelter Options -- Volume II: Detailed Analysis, ANL/EES-TM-227 (Vol. II), prepared for Federal Emergency Management Agency by Argonne National Laboratory, Argonne, IL, March 1982b.

Sartor, J.D., P.D. LaRiviere, H. Lee, and J.I. Pond, The Design and Performance of a Fallout-Tested Manned Shelter Station and Its Suitability as a Single-Family Shelter, USNRDL-TR-647 (AD-609734), U.S. Naval Radiological Defense Laboratory, San Francisco, CA, April 1963.

Sartori, L., "Effects of Nuclear Weapons," Physics Today 36 (3), pp. 32-41 (March 1983).

Sawyer, H.A., "Economic Blast Shelter Project," Journal of Practical Civil Defence (United Kingdom), No. 15, pp. 10-15 (July/August 1985).

Sawyer, H.A., "Economy Blast Shelter -- Family Style," Survive (now Journal of Civil Defense) 2 (4), pp. 10-15 (July/August 1969).

Sawyers, K.N., and F.M. Chilton, Ground Shock and the Survival of the Contents of Personnel Shelters: Application of Generalized Ray Analysis to Prediction of Ground Motion from Nuclear Bursts, SRI Project 4949-432 (AD-671642), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, November 1967.

Schmidt, L.A., A Study of Twenty-Four Nationwide Fallout Patterns from Twelve Winds, IDA Paper No. P-1604 (AD-A104993), prepared for Federal Emergency Management Agency by Institute for Defense Analyses, Arlington, VA, September 1981.

Schmidt, L.A., A Sensitivity Analysis of Urban Blast Fatality Calculations, HQ-71-12378 (AD-728139), Institute for Defense Analyses, Arlington, VA, January 1971.

Schmitz, R., "Shelters -- General Development," AEGIS International (Switzerland) 3 (1), pp. 35-36 (February/March 1984).

Schmoke, M.A., and W.J. Post, Experimental Evaluation of DCPA Standard Method Calculations for Basement Core Structures, BRL-R-1736 (AD-784599), U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, August 1974.

Schuman, W.J., Jr., A Failure Criterion for Blast Loaded Cylindrical Shells, BRL-R-1292 (AD-628289), U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, May 1965.

Scott, C.D., and J.M. Holmes, Emergency Environmental Control System for The Tunnel Grid Shelter, ORNL-TM-1067, Oak Ridge National Laboratory, Oak Ridge, TN, January 1965.

Selheimer, H.E., Proceedings of Eric H. Wang Symposium on Protective Structures Technology (held at Kirtland Air Force Base, New Mexico, on 21-23 July 1970, Volume I), AFWL-TR-71-193-Vol-1 (AD-775467), Air Force Weapons Laboratory, Kirtland Air Force Base, NM, March 1971.

Sevin, E., S. Shenkman, and E. Welch, Ground Shock Isolation of Buried Structures, AFSWC-TR-61-51 (AD-263870), U.S. Air Force Special Weapons Center, Kirtland AFB, NM, July 1961.

Shapira, H.B., G.A. Cristy, S.E. Brite, and M.B. Yost, Cost and Energy Comparison Study of Above- and Belowground Dwellings, ORNL/CON-91 (DE-83-017406), Oak Ridge National Laboratory, Oak Ridge, TN, August 1983.

Shaw, A., Slanting Design: A Pilot Program (Final Report, October 1981 - November 1985), AD-A160689, prepared for Federal Emergency Management Agency by American Institute of Architects' Foundation, Washington, DC, October 1985.

Shepherd, A.D., et al., Bulgur Wafer and Adjuncts for Fallout Shelter Rations (A report of research conducted July 1962-June 1963), AD-431930, prepared for Office of Civil Defense by U.S. Department of Agriculture, Western Regional Research Laboratory, Albany, CA, December 1963.

Shepherd, A.D., D.V. Beavers, R.E. Ferrel, R.J. Horvat, H.Ng, W.G.Lane, and S.E. Allen, Bulgur Wafer and Adjuncts for Fallout Shelter Rations (A report of research conducted July 1964-June 1965), AD-626984, prepared for Office of Civil Defense by U.S. Department of Agriculture, Western Regional Research Laboratory, Albany, CA, 1964.

Shepherd, A.D., R.E. Ferrel, R.J. Horvat, H. Ng, and W.G. Lane, Bulgur Wafer and Adjuncts for Fallout Shelter Rations (A report of research conducted July 1964-June 1965), AD-626984, prepared for Office of Civil Defense by U.S. Department of Agriculture, Western Regional Research Laboratory, Albany, CA, November 1965.

Shepherd, A.D., R.J. Horvat, and H. Ng, Bulgur Wafer and Adjuncts for Fallout Shelter Rations (A report of research conducted July 1966-June 1967), AD-662052, prepared for Office of Civil Defense by U.S. Department of Agriculture, Western Regional Research Laboratory, Albany, CA, November 1967.

Shepherd, A.D., R.J. Horvat, H. Ng, and W.G. Lane, Bulgur Wafer and Adjuncts for Fallout Shelter Rations (A report of research conducted July 1965-June 1966), AD-651224, prepared for Office of Civil Defense by U.S. Department of Agriculture, Western Regional Research Laboratory, Albany, CA, June 1966.

Shimizu, B., H.K. Elder, S. Shepetys, and R.A. Williamson, Parametric Study of Small Personnel Blast Shelters, HN-207, prepared for U.S. Atomic Energy Commission by Holmes and Narver, Inc., Los Angeles, CA, October 1969.

Shimizu, B., R.C. Snow, and R.A. Williamson, Hardness Study of Proposed Washington Metropolitan Area Rapid Transit System, HN-202, prepared for Union Carbide Corporation by Holmes and Narver, Inc., Los Angeles, CA, June 1969.

Shontz, W.D., Operational Capabilities of Community Fallout Shelter Systems (Final Report), AIR-C98-4/63-FR (AD-692819), prepared for the Office of Civil Defense by American Institutes for Research, San Mateo, CA, April 1963.

Shumway, B. W., and A. L. Frank, Angular Radiation Characteristics of Rough Surfaces Contaminated with Fallout Simulant, USNRDL-TR-68-37 (AD-670480), U.S. Naval Radiological Defense Laboratory, San Francisco, CA, February 1968.

Sibley, B., "Swiss Civil Defense -- A Model for Britain and the U.S.?" Journal of Civil Defense 19 (1), p. 8 (February 1986).

Sibley, B., "They Do Test Shelters!" Journal of Practical Civil Defence (United Kingdom), No. 17, pp. 12-17 (November/December 1985).

Sibley, B., "Metal Shelter Design," Journal of Practical Civil Defence (United Kingdom), No. 10, pp. 14-20 (September/October 1984).

Sibley, B., "Home-Made Shelter," Journal of Practical Civil Defence (United Kingdom), No. 7, pp. 17-23 (March/April 1984).

Sibley, B., "Transform Your Cellar into a Shelter -- Part II (Making a Blast-Proof Hatch)," Protect and Survive Monthly (United Kingdom) 1 (12), pp. 21-23 (December 1981).

Sibley, B., "Transform Your Cellar into A Shelter -- Part I," Protect and Survive Monthly (United Kingdom) 1 (11), pp. 12-14 (November 1981).

Sibley, B., "Project Simplex," Protect and Survive Monthly (United Kingdom) 1 (10), pp. 18-20 (October 1981).

Sinnamon, G.K., W.J. Austin, and N.M. Newmark, Air Blast Effects on Entrances and Air Intakes of Underground Installations (Operation UPSHOT-KNOTHOLE, Project 3.7), WT-726, University of Illinois, Urbana, IL, February 1955.

Sinnamon, G.K., R.E. Woodring, N.M. Newmark, and F. Matsuda, Behavior of Underground Structures Subjected to an Underground Explosion (Operation TEAPOT -- Project 3.3.2), WT-1126, University of Illinois, Urbana, IL, October 1957.

Sisson, G.N., "Underground for Nuclear Protection," Underground Space 4 (6), pp. 341-348 (May/June 1980).

Sisson, G.N., "Beneath the Surface -- Cheaper, Safer, More Efficient Structures," Emergency Planning Digest (Canada) 4 (6), pp. 5-7 (November/December 1977).

Slawson, T.R., H.M. Taylor, Jr., F.D. Dallriva, and S.A. Kiger, Structural Elements Tests in Support of the Keyworker Blast Shelter Program, Technical Report SL-85-8, prepared for Federal Emergency Management Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, October 1985.

Smith, E.F., and D.R. Denton, Recommended Long-Range Research Program for Blast-Loaded Structures, Miscellaneous Paper No. 1-825 (AD-748092), prepared for Office of Civil Defense in cooperation with Office of Chief of Engineers and Stanford

Research Institute by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, November 1966.

Smith, J.B., E.W. Cousins, M.J. Miller, and R.M. Newman, Fire Safety Upgrading for Fallout Shelters in Building (Final Report), FMRC Serial No. 15903 (AD-610819), prepared for Office of Civil Defense by Factory Mutual Research Corporation, Norwood, MA, November 1964.

Smith, J.B., E.W. Cousins, and R.M. Newman, Fire Hazard to Fallout Shelter Occupants: A Classification Guide (Final Report), FMRC Serial No. 15328 (AD-600261), prepared for Office of Civil Defense by Factory Mutual Research Corporation, Norwood, MA, April 1964.

Smith, M.C., Illumination in Group Shelters (Final Report - Part II), AD-404091, prepared for Office of Civil Defense by Sanders and Thomas, Inc., Pottstown, PA, March 1963.

Smith, M.C., and W.J. Wendel, Illumination in Group Shelters (Final Report - Part I), AD-404090, prepared for Office of Civil Defense by Sanders and Thomas, Inc., Pottstown, PA, January 1963.

Smith, R.W., and M.A. Lasky, Planning Guides for Dual-Purpose Shelters, AIR-C-93-7/63-TR (AD-412342), American Institute for Research, Pittsburgh, PA, July 1963.

Smith, R. W., and C. A. Madson, Psychological, Engineering, and Physiological Evaluation of Shelter Equipment and Procedures (Volume III -- Habitability Studies), GARD Report 1292, prepared for Office of Civil Defense by General American Transportation Corporation, General American Research Division, Niles, IL, February 1967.

Spangler, B.D., and C.P. Jones, Evaluation of Existing and Potential Hurricane Shelters, SGR-68 (PB-85-217909), Florida Sea Grant College, Gainesville, FL, November 1984.

Spencer, L.V., "Structure Shielding Against Initital Radiations from Nuclear Explosions: I. Attenuation of Air Secondary and Fission Product Gamma Rays," Nuclear Science and Engineering 57 (2), pp. 129-154 (June 1975).

Spencer, L.V., Structure Shielding Against Fallout Radiation From Nuclear Weapons (a National Bureau of Standards Monograph), NBS-Mono-42, U.S. Department of Commerce, National Bureau of Standards, Washington, DC, March 1962.

Spencer, L.V., A.B. Chilton, and C.M. Eisenhauer, Structure Shielding Against Fallout Gamma Rays from Nuclear Detonations, NBS-SP-570 (PB-81-110389), U.S. Department of Commerce, National Bureau of Standards, Washington, DC, September 1980.

Spring, R., and C.H. McDonnell, *An Experimental Evaluation of Roof Reduction Factors Within a Multi-Story Structure*, PSDC-TR-16, Supplement No. 1 (AD-661091), prepared for Office of Civil Defense through the Protective Structures Development Center by CONESCO, a Division of Flow Corporation, Watertown, MA, April 1967.

Staff of Journal of Civil Defense, "Private Shelter: Option for the Wary" *Journal of Civil Defense* *13* (4), pp. 24-28 (August 1980).

Stanford Research Institute, *Low Cost Family Shelters*, prepared for Office of Civil Defense by Stanford Research Institute, Emergency Planning Research Center, Menlo Park, CA, October 1961.

Starbird, A.W., J.D. Velletri, R.L. MacNeil, and J.F. Batter, *The Effect of Interior Partitions on the Dose Rate in a Multistory Windowless Building*, TO-B63-6 (AD-402685), prepared for Office of Civil Defense by Technical Operations Research, Burlington, MA, January 1963.

Stepanek, O.J., *Distribution of Slantable Construction* (Final Report), IITRI Project J6151 (AD-705387), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, March 1970.

Stephens, J., *MISER'S BLUFF; Swedish Personnel Shelter (SH 16 Vault) Phase II, Event 2*, DNA-POR-7022 and WT-7022, prepared for Defense Nuclear Agency by Eric H. Wang Civil Engineering Research Facility, Albuquerque, NM, June 1979.

Stephenson, J.M., *Cooling Analyses for Protective Structures Located Above and Below Ground*, NCEL-TR-493, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, November 1966.

Stephenson, J.M., *Test of German Sand-Type Filter*, NCEL-TR-263, U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, November 1963.

Stephenson, J.M., and R.S. Chapler, *Preliminary Tests of the Stephenson Valve*, NCEL-TN-491 (AD-400309), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, March 1963.

Sterling, R., R. Aiken, and J. Carmody, *Earth Sheltered Housing: Code, Zoning and Financing Issues* (Revised Edition), published for the University of Minnesota, Underground Space Center, by Van Nostrand Reinhold Company, New York, NY, 1981.

Stevenson, J.D., and J.A. Havers, Entranceways and Exits for Blast-Resistant Fully-Buried Personnel Shelters, IITRI Project No. M6064/3 (AD-636048), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, September 1965.

Stone, H., S.M. Oliver, J.M. Kloehn, and R.C. Singleton, Acceptability of Shelter Rations in Combination with Adjuncts (Interim Report), SRI Project 4949-500 (AD-638630), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, April 1966.

Stone, H., S.M. Oliver, and R.C. Singleton, Acceptability of Shelter Rations in Combination with Adjuncts (Interim Report: April 1966 - February 1967), SRI Project 1919-500 (AD-651944), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, March 1967.

Streuli, F., "Emergency Power Installations in Shelters," AEGIS International (Switzerland) 1 (4), pp. 32-39 (August/September 1982).

Strode, J.D., Jr., et al., Proceedings of the MISERS BLUFF Phase II Results Symposium 27-29 March 1979 (Volume I), DNA-POR-7013-1 (WT-7013-1), Defense Nuclear Agency, Kirtland Air Force Base, NM, September 1979a.

Strode, J.D., Jr., et al., Proceedings of the MISERS BLUFF Phase II Results Symposium 27-29 March 1979 (Volume II), DNA-POR-7013-2 (WT-7013-2), Defense Nuclear Agency, Kirtland Air Force Base, NM, September 1979b.

Strode, J.D., Jr., et al., Proceedings of the MISERS BLUFF Phase II Results Symposium 27-29 March 1979 (Volume I), DNA-POR-7013-3 (WT-7013-3), Defense Nuclear Agency, Kirtland Air Force Base, NM, September 1979c.

Strohecker, J.W., "Thermal Threat to a Sheltered Population," pp. 228-241 in Annual Progress Report -- Civil Defense Research Project, March 1966 - March 1967, ORNL-4184 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, December 1967.

Strohecker, J.W., "The Thermal Threat to Sheltered Populations," pp. 153-165 in Annual Progress Report -- Civil Defense Research Project, March 1965 - March 1966, ORNL-TM-1531 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, November 1966.

Strope, W.E., Evaluation of Countermeasure System Components and Operational Procedures (Operation PLUMBBOB, Project 32.3), WT-1464, U.S. Naval Radiological Defense Laboratory, San Francisco, CA, August 1958.

Strope, W.E., et al., Preliminary Report on the Shelter Occupancy Test of 25-29 July 1960, USNRDL-TR-502, U.S. Naval Radiological Defense Laboratory, San Francisco, CA, March 1961.

Strope, W.E., and J.F. Devaney, Effectiveness of Civil Defense Systems, AD-A078528, prepared for Defense Civil Preparedness Agency by Center for Planning and Research, Inc., Palo Alto, CA, June 1979.

Strope, W.E., and J.F. Devaney, Methods of Estimating the Effectiveness and Cost of Civil Defense Program Elements, AD-A057343, prepared for Defense Civil Preparedness Agency by Center for Planning Research, Palo Alto, CA, February 1978.

Strope, W.E., J.F. Devaney, R.K. Laurino, and S. Wengrovitz, Multi-Hazard Shelter Incentive Programs, AD-A159719, prepared for the Federal Emergency Management Agency by Center for Planning and Research, Inc., Palo Alto, CA, September 1985.

Strope, W.E., H.S. Etter, R.A. Golbeck, R.H. Heiskell, and J.H. Sheard, Preliminary Report on the Shelter Occupancy Test of 3-17 December 1959, USNRDL-TR-418, U.S. Naval Radiological Defense Laboratory, San Francisco, CA, May 1960.

Strope, W.E., H.S. Etter, D.P. Schultze, and J.I. Pond, The Family Occupancy Test of 4-6 November 1960, USNRDL-TR-578, U.S. Naval Radiological Defense Laboratory, San Francisco, CA, August 1962.

Strope, W.E., L.G. Porteous, and A.L. Greig, Specifications and Costs of a Standardized Series of Fallout Shelters, USNRDL-TR-366, U.S. Naval Radiological Defense Laboratory, San Francisco, CA, October 1959.

Stubbs, I.R., Blast and Impact Exposure of Existing Structural Fire Protection Schemes (Final Report), AD-626040, prepared for Office of Civil Defense by T.Y. Lin and Associates, Van Nuys, CA, June 1965.

Sullivan, R.J., et al., Civil Defense Needs of High-Risk Areas of the United States (Revision A), SPC-409-Rev-A (AD-A067231), prepared for the Defense Civil Preparedness Agency by System Planning Corporation, Arlington, VA, March 1979.

Sullivan, R.J., W.M. Heller, and E.C. Aldridge, Jr., Candidate U.S. Civil Defense Programs, Report 342 (AD-A052366), prepared for Defense Civil Preparedness Agency by System Planning Corporation, Arlington, VA, March 1978.

Summers, R.L., and Z.G. Burson, Experimental Evaluation of Techniques for Improving Fallout Protection in Home Basements, CEX-65.5, U.S. Atomic Energy Commission, Washington, DC, October 1966.

Svaeri, O.W., and M.M. Dembo, Simulated Occupancy Tests and Air Distribution in a 480-Person Community Fallout Shelter (Final Report), PSDC-TR-23 (AD-666213), prepared for Office of Civil Defense by Protective Structures Development Center, Washington, DC, 1965.

Svaeri, O.W., and N.I. Stein, Air Distribution Studies in Multi-Room Shelter (Final Report), PSDC-TR-21/22 (AD-667911), prepared for Office of Civil Defense by Protective Structures Development Center, Washington, DC, March 1967.

Takata, A. N. and T. E. Waterman, Fire Laboratory Tests - Phase II: Interaction of Fire and Simulated Blast Debris (Final Report), IITRI Project J6217/2 (AD-743210), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, February 1972.

Tansley, R.S., Upgrading Structures for Host and Risk Area Shelters, SSI-8144B-6, prepared for Federal Emergency Management Agency by Scientific Service, Inc., Redwood City, CA, December 1985.

Tansley, R.S., and R.D. Bernard, Shelter Upgrading Manual: Key Worker Shelters (Final Report), SSI-8012-7 (AD-A100511), prepared for Federal Emergency Management Agency by Scientific Service, Inc., May 1981.

Tansley, R.S., R.D. Bernard, G.J. Cuzner, and C. Wilton, Research on Upgrading Structures for Host and Risk Area Shelters - Phase II (Final Report), SSI-8144-12 (AD-A129880), prepared for Federal Emergency Management Agency by Scientific Service, Inc., Redwood City, CA, May 1983.

Tansley, R.S., G.J. Cuzner, and C. Wilton, Research on Upgrading Structures for Host and Risk Area Shelters (Final Report), SSI-8144-7 (AD-A121769), prepared for Federal Emergency Management Agency by Scientific Service, Inc., Redwood City, CA, September 1982.

Tansley, R.S., B.L. Gabrielsen, and G.J. Cuzner, Upgrading of Existing Structures -- Phase I: Shelter Design Options (Final Report), SSI-8012-6 (AD-A100490), prepared for Federal Emergency Management Agency by Scientific Service, Inc., Redwood City, CA, May 1981.

Tansley, R.S., and J.V. Zaccor, Testing of Shelter Design and Industrial Hardening Concepts at the MILL RACE Event (Final Report), SSI-8115-4 (AD-A110919), prepared for Federal Emergency Management Agency by Scientific Service, Inc., Redwood City, CA, January 1982.

Tate, J. N., Jr., R. D. Mathews, and H. Stone, New Ration Concepts (Final Report), SRI Project 6300-160 (AD-684936), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park CA, February 1969.

Taylor, D.W., and J.O. Gonzalez, Air Distribution in a Multi-Room Shelter Using a Package Ventilation Kit, PSDC-TR-17 (AD-633916), prepared for Protective Structures Development Center by University of Florida, Engineering and Industrial Experiment Station, Gainesville, FL, July 1965.

Temet Oy (A Finnish Company), A Case Example about the Use of Blast Valves and a Concrete Tunnel in Blast Wave Attenuation, Helsinki, Finland, July 1980.

Tener, R.K., Model Study of a Buried Arch Subjected to Dynamic Loading, Technical Report No. 1-660, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, November 1964.

Terrell, C.W., A.J. Jerri, and R.O. Lyday, Jr., Radiation Streaming in Ducts and Shelter Entranceways (Final Report), NBy-3185 and ARF-1158A02-7, prepared for U.S. Naval Civil Engineering Laboratory by Armour Research Foundation of Illinois Institute of Technology, Chicago, IL, April 1962.

Thorne, B.J., and J.W. Berglund, POLLYANNA: A Three Dimensional Structure/Media Interaction Computer Program, AFWL-TR-77-12, prepared for U.S. Air Force Special Weapons Laboratory by University of New Mexico, Albuquerque, NM, January 1968.

Thorsen, G.W., "High Bank Instead of High Rise -- An Earth-Sheltered Approach to Medium Density Housing," Underground Space 5 (3), pp. 149-151 (November/December 1980).

Titov, M.N., et al., Civil Defense, Moscow -- 1974 (translated from Russian by Joint Publication's Research Service, Arlington, VA; edited by G.A. Cristy), ORNL-TR-2845, Oak Ridge National Laboratory, Oak Ridge, TN, July 1975.

Tolman, D.F., R.O. Lyday, and E.L. Hill, Estimated Characteristics of NFSS Inventory (Statistical Classification Report), RTI Project No. 43U Research Triangle Institute, Research Triangle Park, NC, December 1973.

Trayser, D.A., L.J. Flanigan, and S.G. Talbert, Minimum Requirements for Auxiliary Power Systems for Community Shelters, AD-603068, Battelle Memorial Institute, Columbus, OH, July 1964.

Trayser, D.A., G.M. Hein, and W.C. Ellis, Deterioration of Fuels and Fuel-Using Equipment (Final Report), AD-662266, prepared for Office of Civil Defense by Battelle Memorial Institute, Columbus, OH, August 1967.

T.Y. Lin and Associates, A Computer Program to Analyze the Dynamic Response of High Rise Building to Nuclear Blast Loading - Volume I (Professional Guide Series Review Draft), PG-80-18-1, prepared for Office of Civil Defense by T.Y. Lin and Associates, Van Nuys, CA, February 1964a.

T.Y. Lin and Associates, A Computer Program to Analyze the Dynamic Response of High Rise Buildings to Nuclear Blast Loading - Volume II (Professional Guide Series Review Draft), PG-80-18-2, prepared for Office of Civil Defense by T.Y. Lin and Associates, Van Nuys, CA, February 1964b.

Uher, R.A., The Role of a Blast Shelter System in Strategic Defense, ORNL-TM-2134, Oak Ridge National Laboratory, Oak Ridge, TN, January 1969.

Uher, R.A., "Blast Shelter Systems with a Light Area Ballistic Missile Defense," pp. 22-35 in Annual Progress Report -- Civil Defense Research Project, March 1967 - March 1968, ORNL-4284 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, November 1968.

Uher, R.A., and M. Noojin, "Effectiveness of Active/Passive Defense Systems," pp. 382-400 in Annual Progress Report -- Civil Defense Research Project, March 1966 - March 1967, ORNL-4184 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, December 1967.

Ullrich, C.R., and D.J. Hagerty, "Developing Underground Space in Louisville, Kentucky," Underground Space 8 (3), pp. 196-205 (1984).

Ullrich, G.W., "A Review of Present Estimates of Near Surface Ground Motions from Nuclear Detonations at or Near the Earth's Surface," pp. 7-30 in Proceedings of the Nuclear Blast and Shock Symposium (held November 28-30, 1978) Volume II, DNA-4794-2 (AD-A073766), prepared for Defense Nuclear Agency by General Electric -- TEMPO, Santa Barbara, CA, December 1978.

University of Arizona, Cost Studies in Protective Construction Systems - General Studies in Costing Techniques with Specific Application to Shelter Systems for Tucson, Arizona, and Houston, Texas (Final Report), Subcontract 138-4, prepared for Institute for Defense Analyses, by University of Arizona Engineering Research Laboratory, Tucson, AZ, January 1965.

University of Arizona, Proceedings of the Symposium on Soil-Structure Interaction, Tucson, Arizona, June 8-11, 1964, AD-610549 sponsored by the Office of Civil Defense, prepared by the University of Arizona, Engineering Research Laboratory, Tucson, AZ, September 1964.

University of Arizona, Local Civil Defense Systems -- A Study of Counterforce Defense Systems Methodology Applied to Tucson, Arizona, and Environs (Final Report), AD-603216, University of Arizona Engineering Research Laboratory, Tucson, AZ, June 1964.

University of Minnesota, Earth Sheltered Structures Fact Sheet 4: Waterproofing Considerations and Materials, ORNL/SUB-7849/04, prepared for U.S. Department of Energy through Oak Ridge National Laboratory by University of Minnesota, Underground Space Center, Minneapolis, MN, September 1981.

University of Minnesota, Earth Sheltered Structures Fact Sheet 3: Waterproofing Techniques, ORNL/SUB-7849/03, prepared for U.S. Department of Energy through Oak Ridge National Laboratory by University of Minnesota, Underground Space Center, Minneapolis, MN, December 1980.

Urban Land Institute, Civil Defense Shelters for Homes Associates (A Supplement to ULI Technical Bulletin 50), AD-452152, Washington, DC, October 1964.

URS Research Company, A Study to Assess the Magnitude of OCD Foundation Problems Pertaining to Nuclear Weapons (Final Report), URS-693-7 (AD-712311), prepared for Office of Civil Defense by URS Research Company, San Mateo, CA, July 1970.

U.S. Army Corps of Engineers, Design of Underground Installations in Rock -- Space Layouts and Excavation Methods (Engineering and Design Manual), EM-10-345-433, Washington, DC, April 1961.

U.S. Army Corps of Engineers, Design of Underground Installations in Rock -- Tunnels and Linings (Engineering and Design Manual), EM-10-345-432 (AD-260604), Washington, DC, January 1961.

U.S. Army Corps of Engineers, Design of Structures to Resist the Effects of Atomic Weapons -- Multistory Frame Buildings (Engineering and Design Manual), EM-10-345-418, Washington, DC, January 1960a.

U.S. Army Corps of Engineers, Design of Structures to Resist the Effects of Atomic Weapons -- Arches and Domes (Engineering and Design Manual), EM-10-345-420 (AD-419943), Washington, DC, January 1960b.

U.S. Army Corp of Engineers, Design of Structures to Resist the Effects of Atomic Weapons -- Buried and Semiburied Structures (Engineering and Design Manual), EM-10-345-421 (AD-419944), Washington, DC, January 1960c.

U.S. Army Corp of Engineers, *Design of Structures to Resist the Effects of Atomic Weapons -- Weapons Effects Data* (Engineering and Design Manual), EM-10-345-413, Washington, DC, July 1959.

U.S. Army Corps of Engineers, *Design of Structures to Resist the Effects of Atomic Weapons -- Shear Wall Structures* (Engineering and Design Manual), EM-10-345-419, Washington, DC, 1959.

U.S. Army Corps of Engineers, *Design of Structures to Resist the Effects of Atomic Weapons -- Single-Story Frame Buildings* (Engineering and Design Manual), EM-10-345-417, Washington, DC, January 1958.

U.S. Army Corps of Engineers, *Design of Structures to Resist the Effects of Atomic Weapons -- Strength of Materials and Structural Elements* (Engineering and Design Manual), EM-10-345-414 (AD-421101), Washington, DC, March 1957a.

U.S. Army Corps of Engineers, *Design of Structures to Resist the Effects of Atomic Weapons -- Principles of Dynamic Analysis and Design* (Engineering and Design Manual), EM-10-345-415, Washington, DC, March 1957b (includes Change 1).

U.S. Army Corps of Engineers, *Design of Structures to Resist the Effects of Atomic Weapons -- Structural Elements Subjected to Dynamic Loads* (Engineering and Design Manual), EM-10-345-416, Washington, DC, March 1957c (includes Change 1).

U.S. Army Corps of Engineers, *Fundamentals of Protective Design* (Engineer Manual for War Department Construction), AD-421088, Washington, DC, 1946.

U.S. Army Engineer School, *Protective Construction by Proved Components* (extract technical report), Technical Manual 1689-TR, Fort Belvoir, VA, no date.

U.S. Army Engineer Waterways Experiment Station, *Attenuation o Airblast in Protective Structures*, Miscellaneous Paper No. 1-608 (AD-450996), Vicksburg, MS, November 1963.

U.S. Department of the Army, *Designing Facilities to Resist Nuclear Weapons Effects -- Hardness Verification*, TM-5-858-6, Washington, DC, August 1984.

U.S. Department of the Army, *Designing Facilities to Resist Nuclear Weapons Effects -- Weapons Effects*, TM-5-858-2, Washington, DC, July 1984a.

U.S. Department of the Army, *Designing Facilities to Resist Nuclear Weapon Effects - Structures*, TM-5-858-3, Washington, DC, July 1948b.

U.S. Department of the Army, Designing Facilities to Resist Nuclear Weapons Effects -- Shock Isolation Systems, TM-5-858-4, Washington, DC, June 1984.

U.S. Department of the Army, Designing Facilities to Resist Nuclear Weapons Effects -- Air Entrainment, Fasteners, Penetration Protection, Hydraulic-Surge Protective Devices, EMP Protective Devices, TM-5-858-5, Washington, DC, December 1983.

U.S. Department of the Army, Designing Facilities to Resist Nuclear Weapons Effects -- Facility System Engineering, TM-5-858-1, Washington, DC, October 1983a.

U.S. Department of the Army, Designing Facilities to Resist Nuclear Weapons Effects -- Facility Support Systems, TM-5-858-7, Washington, DC, October 1983b.

U.S. Department of Health, Education, and Welfare, Medical Care in Shelters, AD-423696, Washington, DC, December 1963.

U.S. Department of the Navy, Bureau of Yards and Docks, Personnel Shelters and Protective Construction, NAVDOCKS-P-81, Washington, DC, September 1961 (including changes: CH-1, February 7, 1962, and CH-2, July 9, 1962).

U.S. Naval Civil Engineering Laboratory, Protective Shelter Systems: An Annotated Bibliography of U.S. Naval Civil Engineering Laboratory Publications, NCEL-TN-562, Port Hueneme, CA, February 1964.

"U.S. Shelter Manufacturer Enters UK-European Market," Protect and Survive Monthly (United Kingdom) 2 (3), pp. 30-31 (March 1982).

U.S. Strategic Bombing Survey, The Effects of the Atomic Bomb on Nagasaki, Japan (Volumes I, II, and III), Pacific War Report No. 93, Physical Damage Division, Washington, DC, June 1947.

U.S. Strategic Bombing Survey, The Effects of the Atomic Bomb on Hiroshima, Japan (Volumes I, II, and III), Pacific War Report No. 92, Physical Damage Division, Washington, DC, May 1947.

U.S. Strategic Bombing Survey, Field Report Covering Air-Raid Protection and Allied Subjects in Nagasaki, Japan, Pacific War Report No. 5, Civilian Defense Division, Washington, DC, February 1947a.

U.S. Strategic Bombing Survey, Air-Raid Protection and Allied Subjects in Japan (Final Report), Pacific War Report No. 11, Civilian Defense Division, Washington, DC, February 1947b.

U.S. Strategic Bombing Survey, *Public Air Raid Shelters in Germany*, European War Report No. 154, Physical Damage Division, Washington, DC, January 1947.

U.S. Strategic Bombing Survey, *The Effects of Atomic Bombs on Hiroshima and Nagasaki*, Pacific War Report No. 3, Office of the Chairman, Washington, DC, June 1946.

U.S. Strategic Bombing Survey, *Air-Raid Protection and Allied Subjects in Japan* (Summary Report), Pacific War Report No. 10, Civilian Defense Division, Washington, DC, March 1946.

U.S. Strategic Bombing Survey, *Air-Raid Protection and Allied Subjects in Germany* (Final Report), European War Report No. 40, Civilian Defense Division, Washington, DC, October 1945.

Vaile, R.B., Jr., *Isolation of Structures from Ground Shock* (Operation PLUMBBOB, Project 3.5), WT-1424, Stanford Research Institute, Menlo Park, CA, April 1960.

Vaile, R.B., Jr., and L.D. Mills, *Evaluation of Earth Cover as Protection to Aboveground Structures* (Operation TEAPOT, Project 3.6), WT-1128, U.S. Department of the Navy, Washington, DC, December 1956.

Vermes, G., and G.P. Wachtell, *Manual Blower Development* (Final Report), F-B1983 (AD-623840), prepared for Office of Civil Defense by the Franklin Institute Research Laboratories, Philadelphia, PA, September 1965.

Vernon, J.A., *Project Hideaway - A Pilot Feasibility Study of Fallout Shelters for Families*, Research Contract No. CMD-SR-60-15, prepared for Office of Civil Defense Mobilization by Princeton University, Department of Psychology, Princeton, NJ, December 1959.

Viecelli, J., *Air Blast Protection in Tunnels*, UCRL-14848-T, Lawrence Radiation Laboratory, Livermore, CA, March 1966.

Vodvarka, F.J., and F. Salzberg, *Full Scale Burns in Urban Areas Shelter Experiments* (Final Technical Report), IITRI Project J6009 (AD-697271), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, June 1969.

Vortman, L.J., *A Risk-Oriented Approach to Protection from Nuclear Weapons*, SC-4689(RR), prepared for U.S. Atomic Energy Commission by Sandia Corporation, Albuquerque, NM, September 1962a.

Vortman, L.J., *Cost-Effectiveness of Sheltering the Civil Population of a City with an Adjacent Military Target*, SCDC-35X, Sandia Corporation, Albuquerque, NM, September 1962b.

Vortman, L.J., et al., Evaluation of Various Types of Personnel Shelters Exposed to an Atomic Explosion (Operation TEAPOT, Project 34.1 and 34.3), WT-1218 (AD-A073524), Sandia Corporation, Albuquerque, NM, and Federal Civil Defense Administration, Battle Creek, MI, May 1956.

Vortman, L.J., et al. Effects of an Atomic Explosion on Group and Family Type Shelters (Operation TEAPOT, Projects 34.1 and 34.3), WT-1161, Sandia Corporation, Albuquerque, NM, and Federal Civil Defense Administration, Battle Creek, MI, January 1957.

Wade, H., Building Underground: The Design and Construction Handbook for Earth-Sheltered Houses, published by Rodale Press, Emmaus, PA, 1983.

Walker, L.A., and E.H. Bultmann, Comparison of Static and Dynamic Test Models of Horizontal Buried Cylinders, DNA-5839F-2, prepared for Defense Nuclear Agency by BDM Corporation, Albuquerque, NM, May 1984.

Wampler, H.W., et al., "A Status and Capability Report on Nuclear Airblast Simulation Using HEST," in Proceedings of the Nuclear Blast and Shock Simulation Symposium, 28-30 November 1978, DNA-4797-P1 (Vol. 1), published by Defense Nuclear Agency, Washington, DC, December 1978.

Ward, D., "Using the Kansas City Underground for Civil Defense: An Alternative to Evacuation of an Urban Population," pp. 65-72 in Underground Space Conference and Exposition (held in Kansas City, MO, June 8, 1981), CONF-810671-1, (1981).

Ward, M., "Concrete Survival," Journal of Practical Civil Defence (United Kingdom), No. 6, pp. 21-19 (January/February 1984).

Ward, M., "Concrete Survival -- Part 8, Compromise Shelters," Journal of Practical Civil Defence (United Kingdom), No. 1, pp. 11-13 (March/April 1983).

Ward, M., "Concrete Survival No. 7, Value for Money," Protect and Survive Monthly (United Kingdom) 2 (3), pp. 16-17 (March 1982).

Warner, W.K., and J.R. Christiansen, Study of the Feasibility of Using Residential Shelters as Group Shelters (Final Report), AD-747313, prepared for Defense Civil Preparedness Agency by Brigham Young University, Department of Sociology, Provo, UT, August 1972.

Waterman, G.S., An Effective Shelter Program, M59-100 (AD-234144), Industrial College of the Armed Forces, Washington, DC, April 1959.

Waterman, T. E., Fire Laboratory Tests; Phase IV -- Effects of Barrier Integrity and Fire Ventilation on Shelter Habitability, Project J6217 (AD-786175), prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, May 1974.

Waterman, T.E., Fire Laboratory Tests -- Phase I: Fires in Blast-Initiated Debris External to Shelters, IITRI-J6217 (AD-759514), prepared for Defense Civil Preparedness Agency by IIT Research Institute, Chicago, IL, February 1973.

Waterman, T.E., Fire Laboratory Tests -- Phase III (Final Report), IITRI Project J6183 (AD-713017), prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, September 1970.

Waterman, T.E., Shelter Habitability in Existing Buildings Under Fire Exposure, AD-637806, prepared for Office of Civil Defense by IIT Research Institute, Chicago, IL, June 1966.

Watt, J.M., Jr., and R.R. Kaufmann, Federal Republic of Germany Structures Test Program, DICE THROW Event (Report 2 -- Construction and Test Data), WES-TR-N-77-2-2 (AD-B032566), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, October 1978.

Watt, J.M., Jr., R.R. Kaufmann, and M.K. McVay, Federal Republic of Germany Structures Test Program, DICE THROW Event (Report 3-- Results of Posttest Analyses), WES-TR-N-77-2-3 (AD-B042708), U.S. Army Engineers, Waterways Experiment Station, Vicksburg, MS, October 1979.

Watt, J.M., Jr., G. Zahlmann, and R.A. Cole, Federal Republic of Germany Structures Test Program, DICE THROW Event (Report 1-- Pretest Planning and Analyses), WES-TR-N-77-2-1 (AD-B019367), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, June 1977.

Weinstein, J.M., The Strategic Implications of Civil Defense, ACN-83012 (AD-A134608), Strategic Studies Institute, U.S. Army War College, Carlisle Barracks, PA, May 1983.

Welch, P., On the Rating of Blast Shelters, HI-389-DP, Hudson Institute, Harmon-on-Hudson, NY, August 1964.

Wellisch, J.B., B.H. Bancroft, T.P. Haney, and R. Sbordone, Further Study of the Adoption-Diffusion Process in Development of Shelter in New Construction, TM-4213/005/00 (AD-703935), System Development Corporation, Santa Monica, CA, February 1970.

Westinghouse Electric Corporation, Development of a Specification for a 75 CFM Gas Particulate Filter Unit for Removing the CBR Contaminants of Warfare from the Air Supplied to Family Shelters (Final Report), AD-296236, prepared for Army Chemical Center by

Westinghouse Research Laboratories, Pittsburgh, PA, September 1962.

White, C.S., et al., Biological Effects of Pressure Phenomena Occurring Inside Protective Shelters Following a Nuclear Detonation (Operation TEAPOT, Project 33.1), WT-1179, Lovelace Foundation for Medical Education and Research, Albuquerque, NM, October 1956.

White, C.S., I.G. Bowen, and D.R. Richmond, A Comparative Analysis of Some of the Immediate Environmental Effects at Hiroshima and Nagasaki, CEX-63.7, prepared for U.S. Atomic Energy Commission by Lovelace Foundation for Medical Education and Research, Albuquerque, NM, August 1964.

White, C.S., I.G. Bowen, and D.R. Richmond, "A Comparative Analysis of Some of the Immediate Environmental Effects at Hiroshima and Nagasaki," Health Physics 10 (3), pp. 89-150 (March 1964).

White, C.S., M.B. Wetherbe, and V.C. Goldizen, The Internal Environment of Underground Structures Subjected to Nuclear Blast -- The Occurrence of Dust (Operation PLUMBBOB, Preliminary Report, Project 33.5), ITR-1447, Lovelace Foundation for Medical Education and Research, Albuquerque, NM, September 1957.

White, R.W., Development of a Tubular Sandbag for Overhead Protection Against Small High-Explosive Superquick Fuze Rounds, Miscellaneous Paper SL-80-16 (AD-B053470), U.S. Army Engineer Waterways Experiment Station, Structures Laboratory, Vicksburg, MS, September 1980.

Whitehill, C. F., H. F. Mullikin, and O. A. Kubal, Ventilation of Fallout Shelters by Induced Draft, AD-621998, prepared for Office of Civil Defense by Montana State University, Mechanical Engineering Department, Bozeman, MT, June 1965.

Wiehle, C.K., Evaluation of Existing Structures, SRI-1219-2 (AD-A011134), prepared for Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA, December 1974.

Wiehle, C.K., Summary of the Dynamic Analysis of the Exterior Walls and Floor Systems of 50 NFSS Buildings, prepared for Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA, June 1974.

Wiehle, C.K., Dynamic Analysis of a Building and Building Elements, SRI-1219-2 (AD-A001387), prepared for the Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA April 1974.

Wiehle, C. K., Shelter Entranceways and Openings (Final Report), SRI Project No. MU-6300-070 (AD-662749), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, September 1967.

Wiehle, C.K., Soil-Structure Interaction Under Dynamic Load; Part I -- Analysis and Correlation, URS-645-7 and DASA-1711 (AD-474964), prepared for Defense Atomic Support Agency by URS Corporation, Burlingame, CA, November 1965.

Wiehle, C.K., and J.L. Bockholt, Dynamic Analysis of Reinforced Concrete Floor Systems, SRI-1219-2 (AD-768206), prepared for Defense Civil Preparedness Agency by Stanford Research Institute, Menlo Park, CA, May 1973.

Wiehle, C.K., and J.L. Bockholt, Blast Response of Five NFSS Buildings, SRI-P-1219 (AD-738547), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, October 1971.

Wiehle, C.K., and J.L. Bockholt, Existing Structures Evaluation -- Part V: Applications (Final Report), SRI Project 6300 (AD-733343) prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, July 1971.

Wiehle, C. K., and J. L. Bockholt, Existing Structures Evaluation -- Part IV: Two-Way Action Walls, SRI Project 6300 (AD-719306), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, September 1970.

Wiehle, C. K., and J. L. Bockholt, Existing Structures Evaluation -- Part I: Walls, SRI Project No. MU-6300-020 (AD-687293), prepared for Office of Civil Defense by Stanford Research Institute, Menlo Park, CA, November 1968.

Wiehle, C.K., and W.L. Durbin, Combined Effects of Nuclear Weapons on NFSS Type Structures (Final Report), URS-658-3, prepared for Office of Civil Defense by URS Corporation, Burlingame, CA, September 1966.

Williams, C.J., J.T. Huffaker, H.M. Abele, and F.S. Patton, "Dallas Dual-Use Truck Tunnel," pp. 268-284 in Annual Progress Report -- Civil Defense Research Project, March 1966 - March 1967, ORNL-4184 (Part I), Oak Ridge National Laboratory, Oak Ridge, TN, December 1967.

Williams, C.J., and R.P. Kennedy, "Dallas Dual-Use Truck Tunnel with Portable Columns," pp. 124-133 in Annual Progress Report -- Civil Defense Research Project, March 1967 - March 1968, ORNL-4284(Part I), Oak Ridge National Laboratory, Oak Ridge, TN, November 1968.

Williams, D.E., Air Revitalization Unit for Sealed Shelters, NCEL-TR-697 (AD-714163), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, October 1970.

Williams, D.E., Air Revitalization for Sealed Survival Shelters NCEL-TN-987 (AD-681009), U.S. Naval Civil Engineering Laboratory, Port Hueneme, CA, December 1968.

Williams, D.E., and D.N. Pal, Development of High-Capacity Blast Valve for Hardened Naval Shore Facilities, NCEL-TR-745, Naval Civil Engineering Laboratory, Port Hueneme, CA, October 1971.

Williamson, R.A., "Performance and Design of Special Purpose Blast Resistant Structures," Journal of the American Concrete Institute 31 (11), pp. 1171-1190 (May 1960).

Williamson, R.A., and P.H. Huff, Test of Buried Structural-Plate Pipes Subjected to Blast Loading (Operation PLUMBBOB, Project 34.3), WT-1474, Holmes and Narver, Inc., Los Angeles, CA, July 1961.

Willoughby, A.B., C. Wilton, and B. Gabrielsen, Development and Evaluation of a Shock Tunnel Facility for Conducting Full-Scale Tests of Loading Response, and Debris Characteristics of Structural Elements (Summary Report), URS-680-2 (AD-674256), prepared for Office of Civil Defense by URS Corporation, Burlingame, CA, December 1967.

Willoughby, A.B., C. Wilton, B.L. Gabrielsen, and J.V. Zaccor, Loading, Structural Response, and Debris Characteristics of Wall Panels (Final Report), URS-680-5 (AD-693792), prepared for the Office of Civil Defense by URS Research Company, Burlingame, CA, July 1969.

Wilton, C., and B. Gabrielsen, Shock Tunnel Tests of Preloaded and Arched Wall Panels, URS-7030-10 (AD-764263), prepared for Defense Civil Preparedness Agency by URS Research Company, San Mateo, CA, June 1973.

Wilton, C., and B. Gabrielsen, Shock Tunnel Tests of Wall Panels, URS-7030-7 (AD-747331), prepared for Defense Civil Preparedness Agency by URS Research Company, San Mateo, CA, January 1972.

Wilton, C., B. Gabrielsen, J. Edmunds, and S. Bechtel, Loading and Structural Response of Wall Panels, URS-709-4 (AD-711548), prepared for Office of Civil Defense by URS Research Company, San Mateo, CA, November 1969.

Wilton, C., B. Gabrielsen, and P. Morris, Structural Response and Loading of Wall Panels, URS-709-11 (AD-730483), prepared for Office of Civil Defense by URS Research Company, San Mateo, CA, July 1971.

Wilton, C., B.L. Gabrielsen, and R.S. Tansley, Shelter Upgrading Manual: Host Area Shelters (Revisions and Additions) (Final Report), SSI-8012-8 (AD-A100497), prepared for Federal Emergency Management Agency by Scientific Service, Inc., Redwood City, CA, May 1981.

Wilton, C., B. Gabrielsen, and R.S. Tansley, Shelter Upgrading Manual: Host Area Shelters (Final Report), SSI-7815-8 (AD-A085024), prepared for Federal Emergency Management Agency by Scientific Service, Inc., Redwood City, CA, March 1980.

Wilton, C., K. Kaplan, and B.L. Gabrielsen, The Shock Tunnel: History and Results (Volumes I-V), SSI-7618-1 (AD-A055518), prepared for Defense Civil Preparedness Agency by Scientific Service, Inc., Redwood City, CA, February 1968.

Wilton, C., and J.V. Zaccor, Industrial Hardening and Population Blast Shelter Tests at the DIRECT COURSE Event, SSI-8306-5 (AD-A140128), prepared for the Federal Emergency Management Agency by Scientific Service, Inc., Redwood City, CA, March 1984.

Wilton, C., T.C. Zsutty, and A.B. Willoughby, Development of Damage and Casualty Functions for Basement Shelters (Final Report on Phase II), SSI-8143-14 (AD-A133358), prepared for Federal Emergency Management Agency by Science Service, Inc., Redwood City, CA, September 1983.

W.L. Badger Associates, Inc., Study of Processes for the Production of Potable Water from Aqueous Wastes Developed in a Shelter, AD-602416, prepared for the Office of Civil Defense by W.L. Badger Associates, Inc., Ann Arbor, MI, October 1962.

Wong, F.S., and P. Weidlinger, "Design of Underground Shelters Including Soil-Structure Interaction Effects," pp. 174-176 in The Interaction of Non-Nuclear Munitions with Structures (A Symposium held at U.S. Air Force Academy, Colorado, on 10-13 May 1983), SBI-AD-E800/785 (Part 1), (this article is available as AD-P001738), published by University of Florida, Graduate Engineering Center, Eglin AFB, FL, 1983.

Woodring, R.E., G.K. Sinnamon, and N.M. Newmark, Air Blast Effects on Underground Structures (Operation TEAPOT, Project 3.4), WT-1127, University of Illinois, Urbana, IL, and U.S. Army, Protective Construction Branch, Washington, DC, August 1957.

Woodson, S.C., Effects of Shear Stirrup Details on Ultimate Capacity and Tensile Membrane Behavior of Reinforced Concrete Slabs, Technical Report SL-85-4, prepared for Federal Emergency

Management Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, August 1985.

Woodson, S.C., Test and Analyses of 1/4-Scale Upgraded Nine-Bay Reinforced Concrete Basement Models, WES/TR/SL-84-6 (AD-A146813), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, May 1984.

Woodson, S.C., and S.B. Garner, Effects of Reinforcement Configuration on Reserve Capacity of Concrete Slabs, Technical Report SL-85-5, prepared for Federal Emergency Management Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, August 1985.

Woodson, S.C., and M.K. McVay, Test and Evaluation of Upgraded Flat-Plate and Waffle-Slab Floor Systems (Final Report), SL-83-7 (AD-A139005), prepared for Federal Emergency Management Agency by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, December 1983.

Woodson, S.C., T.R. Slawson, and R.L. Holmes, Dynamic Test of a Corrugated Steel Keyworker Blast Shelter (Final Report), SL-86-6, prepared for Federal Emergency Management Agency by U.S. Army Engineer WAterways Experiment Station, Vicksburg, MS, May 1986.

Wright, J.C., A Resource Allocation Model for Shelter Systems Analysis (Final Report), RTI-OU-230-1 (AD-690251), prepared for Office of Civil Defense by Research Triangle Institute, Research Triangle Park, NC, April 1969.

Wright, M.D., et al., Mine Lighting and Ventilation in Crisis, AD-A018783, Research Triangle Institute, Research Triangle Park, NC, October 1975.

Wright, M.D., W. Berryhill, and R.Y. Wallace, Ventilation Surge Techniques, Volume I (Final Report), RTI/2084/00-04F (AD-A109079) prepared for Federal Emergency Management Agency by Research Triangle Institute, Research Triangle Park, NC, December 1981.

Wright, M. D., G. M. Botkin, and E. L. Hill, Natural Thermal Ventilation Experimental Studies (Final Report), RTI-43U-629-3 (AD-785916), prepared for Defense Civil Preparedness Agency by Research Triangle Institute, Research Triangle Park, NC, August 1974.

Wright, M.D., R. Chessin, M. Laney, and L. Cox, State-of-the-Art Assessment -- Shelter Habitability (Final Report), RTI/2265/00-04 (AD-A119825), prepared for Federal Emergency Management Agency by Research Triangle Institute, Research Triangle Park, NC, September 1982.

Wright, M.D., R. Chessin, K. Reeves, and S. York, I, National Underground Mines Inventory, RTI-2507-00-01F (AD-A134607), prepared for the Federal Emergency Management Agency by Research Triangle Institute, Research Triangle Park, NC, October 1983.

Wright, M.D., and E.L. Hill, Development of All Effects Survey Procedures (Final Report), RTI-43U-464-2, prepared for Defense Civil Preparedness Agency by Research Triangle Institute, Research Triangle Park, NC, August 1973.

Wright, M. D., E. L. Hill, and G. M. Botkin, Study of Air Distribution in Large Partitioned Shelters (Final Report), RTI-43U-629-2 (AD-757365), prepared for Defense Civil Preparedness Agency by Research Triangle Institute, Research Triangle Park, February 1973.

Wright, M.D., E.L. Hill, J.S. McKnight, and S.B. York, I, Mine Lighting and Ventilation in Crises (Final Report), RTI-43U-982-1 (AD-A018783), prepared for Defense Civil Preparedness Agency by Research Triangle Institute, Research Triangle Park, NC, October 1975.

Wright, M.D., E.L. Hill, and C.T. Sawyer, Ventilation Kit Application Study, R-OU-400 (AD-706849), prepared for Office of Civil Defense by Research Triangle Institute, Research Triangle Park, NC, February 1970.

Wright, M.D., E.L. Hill, D.F. Tolman, R.O. Lyday, and S.B. York, III, Rural Area Shelter Development Study (Final Report), RTI-43U-464-3 (AD-A016026), prepared for Defense Civil Preparedness Agency by Research Triangle Institute, Research Triangle Park, NC, July 1975.

Wright, M.D., E.L. Hill, and D.R. Whitaker, Study of Air Distribution in Large Single-Room Shelters (Final Report), RTI-43U-629-1 (AD-742684), prepared for Office of Civil Defense by Research Triangle Institute, Research Triangle Park, NC, December 1971.

Wright, M.D., J.L. Warren, D.F. Tolman, R.H. Hill, M.N. Laney, and S.B. York, Development of an Underground Assets Survey (Final Report), RTI-44U-1156, prepared for Defense Civil Preparedness Agency by Research Triangle Institute, Research Triangle Park, NC, September 1976.

Wright, M. D., and S. B. York, I, Development of Shelter Use Plans (Final Report), RTI/1525/00-05F (AD-A067182), prepared for Civil Defense Preparedness Agency by Research Triangle Institute, Research Triangle Park, NC, February 1979.

Wright, M. D., S. B. York, I, D. R. Johnston, and M. N. Laney, *Mine Utilization in Crises -- Planning Manual* (Final Report), RTI-44U-982-2 (AD-A032133), prepared for Defense Civil Preparedness Agency by Research Triangle Institute, Research Triangle Park, NC, September 1976.

Wukasch, E., "Underground Population Defense Structures in China," *Underground Space 7* (1), pp. 16-20 (July/August 1982).

York, S. B., I, and J. G. Armstrong, *Study of Fallout Shelter Ventilation Kit Placement Design* (Final Report), RTI/1703/00-08F (AD-A085165), prepared for Federal Emergency Management Agency by Research Triangle Institute, Research Triangle Park, NC, May 1980.

York, S. B., I, and J. S. McKnight, *Study of Crisis Utilization of Small Shelter Space* (Final Report), RTI-1533/00-05F (AD-A060301), prepared for Defense Civil Preparedness Agency by Research Triangle Institute, Research Triangle Park, NC, August 1978.

York, S. B., I, K. J. Reeves, and R. J. Wallace, *Ventilation: Host and Risk Area Techniques* (Final Report), RTI/2072/00-08F (AD-A114835), prepared for Federal Emergency Management Agency by Research Triangle Institute, Research Triangle Park, NC, April 1982.

York, S. B., I, M. D. Wright, and E. L. Hill, *Alternative Ways of Providing Host Area Fallout Protection* (Final Report),RTI-44-U-988 (AD-A022041), prepared for Defense Civil Preparedness Agency by Research Triangle Institute, Research Triangle Park, NC, December 1975.

Yorulmaz, M., and M. A. Sozen, *Behavior of Single-Story Reinforced Concrete Frames with Filler Walls*, Structural Research Series No. 337, prepared for Office of Civil Defense by University of Illinois, Urbana, IL, May 1968.

Zaccor, J.V., *An Empirical Study of Earth Covered Schools in Oklahoma* (Final Report), SSI-7832-1 (AD-A082506), prepared for Federal Emergency Management Agency by Scientific Service, Inc., November 1979.

Zaccor, J.V., C. Wilton, and R.D. Bernard, *Industrial Hardening: 1980 Technical Report*, SSI-8011-6 (AD-A102621), prepared for the Federal Emergency Management Agency by Scientific Services, Inc., June 1981.

Zilbert, E.R., *The Chinese Nuclear Explosion, N-Nation Nuclear Development and Civil Defense*, AD-614895, Rand Corporation, Santa Monica, CA, April 1965.

Zimmerman, G.P., and C.V. Chester, High Explosive Testing of a Corrugated Metal Blast Shelter with Membrane Blast Doors, ORNL/TM-9289 (DE-85-004109), Oak Ridge National Laboratory, Oak Ridge, TN, December 1984.